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RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF J47 TURBOJET-ENGINE PERFORMANCE

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RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF J47 TURBOJET-ENGINE PERFORMANCE

By E. William Conrad and Adam E. Sobolewski

SUMMARY

An investigation has been conducted in the NACA Lewis altitude wind tunnel to evaluate the performance of the J47 turbojet engine over a range of simulated altitudes from 5000 to 50,000 feet, simulated flight Mach numbers from 0.21 to 0.97, and a complete range of engine speeds. Data are presented to show the effects of altitude at a flight Mach number of 0.21 and of flight Mach number at an altitude of 25,000 feet. The performance data are generalized by two methods to determine the range of flight conditions for which engine performance may be predicted from performance data obtained at a given flight condition.

Engine-performance parameters obtained at a given altitude and flight Mach number could be used to predict engine performance for only a limited range of altitudes and corrected engine speeds. From the engine pumping characteristics presented, jet thrust could be predicted for any desired flight Mach number and exhaust-gas temperature for engine-pressure ratios above approximately 1.4 at altitudes from 5000 to 50,000 feet. The decrease in temperature-limited engine speed with increasing altitude indicated the need for a variable-area exhaust nozzle.

The specific fuel consumption at temperature-limited engine speed and a flight Mach number of 0.21 varied from 1.20 to 1.30 pounds per hour per pound of net thrust over the range of altitudes investigated. A minimum specific fuel consumption of 1.05 pounds per hour per pound of net thrust was obtained at an engine speed of approximately 6400 rpm at altitudes from 15,000 to 45,000 feet. Changes in flight Mach number at rated engine speed had no appreciable effect on specific fuel consumption. At lower engine speeds, however, the specific fuel consumption increased as the flight Mach number was raised.

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At an altitude of 25,000 feet, the internal drag of a windmilling engine varied from 2 percent of the available net thrust at a true airspeed of 200 miles per hour to 15 percent at a true airspeed of 650 miles per hour.

INTRODUCTION

An investigation has been conducted in the NACA Lewis altitude wind tunnel to determine the over-all performance, component performance, and operational characteristics of a J47 turbojet engine over a wide range of simulated flight conditions.

Data are presented in graphical form to show the engine performance over a range of altitudes from 5000 to 50,000 feet and flight Mach numbers from 0.21 to 0.97. The effect of altitude is shown at a flight Mach number of 0.21 and the effect of flight Mach number is shown at an altitude of 25,000 feet. Performance data are generalized by two methods to determine the range of flight conditions for which engine performance may be predicted from performance data obtained at a given flight condition. Curves are presented to show the windmilling characteristics of the engine. All engine performance data obtained in the investigation are also presented in tabular form.

DESCRIPTION OF ENGINE

The J47 turbojet engine used in the altitude-wind-tunnel investigation (fig. 1) has a sea-level static thrust rating of 5000 pounds at an engine speed of 7900 rpm and a turbine-outlet gas temperature of 1275° F. At this rating the air flow is approximately 94 pounds per second. The engine has a 12-stage axial-flow compressor with a pressure ratio of approximately 5.1 at rated engine speed, eight cylindrical direct-flow-type combustion chambers, a single-stage impulse turbine, and a fixed-area exhaust nozzle. The exhaust nozzle, which was used in this investigation and was designated standard, had an outlet area of 280 square inches. This exhaust nozzle produced a turbine-outlet temperature of approximately 1275° F at a flight Mach number of 0.21, an altitude of 5000 feet, and an engine speed of 7900 rpm. The over-all length of the engine excluding the exhaust nozzle is 143 inches, the maximum diameter is approximately 37 inches, and the total weight is 2475 pounds.

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Air enters the engine through an annular inlet (fig. 2) and passes into the compressor through a row of inlet guide vanes. The air is discharged from the compressor through two rows of straightening vanes. From the annular outlet of the compressor, the air flows into the combustion chambers where it is mixed with fuel injected through duplex fuel nozzles. The mixture is burned and the hot gases of combustion flow through the turbine-inlet stator blades, the turbine, and into the atmosphere through the tail pipe and the exhaust nozzle.

INSTALLATION

The engine was mounted on a wing in the test section of the altitude wind tunnel (fig. 1). Dry refrigerated air was supplied to the engine from the tunnel make-up air system through a duct connected to the engine inlet. A frictionless slip joint in the duct made possible the measurement of engine thrust and drag by the tunnel balance scales. The air flow through the duct was throttled from approximately sea-level pressure to a total pressure at the engine inlet corresponding to the desired flight Mach number at a given altitude.

Instrumentation for measuring pressures and temperatures was installed at various stations in the engine (fig. 2). Instrumentation for measuring air flow was installed at the inlet-air-duct venturi throat (station r), the engine inlet (station 1), and the exhaust-nozzle outlet (station 7).

PROCEDURE

Thrust values were calculated from tunnel balance-scale measurements and also from values of gas flow and jet velocity obtained from measurements with the exhaust-nozzle survey rake. The exhaust-nozzle jet-velocity coefficient, defined as the ratio of scale jet thrust to rake jet thrust, is shown as a function of exhaust-nozzle pressure ratio in figure 3. Engine performance is based on thrust values obtained from the balance scales because this method includes the losses resulting from the inefficiency of the exhaust nozzle.

Symbols and methods of calculation are given in the appendix.

Performance data were obtained at the following altitudes and flight Mach numbers:

Altitude (ft)	Flight Mach number
5,000	0.21
15,000	0.21, 0.53
25,000	0.21, 0.53, 0.72, 0.85, 0.97
35,000	0.21, 0.53, 0.72
45,000	0.21, 0.53
50,000	0.21

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Complete ram-pressure recovery at the compressor inlet was assumed in the calculation of flight Mach number. The fuel used was AN-F-32 with a lower heating value of 18,550 Btu per pound. The engine-inlet air temperature was held at approximately NACA standard values for each simulated flight condition except those of high altitude and low Mach number. Engine-inlet air temperatures below 439° R were unobtainable.

RESULTS AND DISCUSSION

All the data obtained in the performance investigation of the engine with a standard exhaust nozzle are compiled in table 1. The engine-inlet pressures and temperatures deviated slightly from the desired inlet conditions. The data presented graphically in nongeneralized form have therefore been adjusted to NACA standard altitude conditions by means of the factors δ_a and θ_a (appendix A).

Engine Performance

Effect of altitude. - Engine-performance data obtained at a flight Mach number of 0.21 at altitudes from 5000 to 50,000 feet are presented to show the effects of altitude on net thrust, air flow, fuel flow, specific fuel consumption, fuel-air ratio, and exhaust-gas total temperature in figure 4. Engine net thrust, air flow, and fuel consumption decreased consistently as the altitude increased (figs. 4(a) to 4(c)). Data obtained at high engine speeds are not shown for an altitude of 15,000 feet because the flight Mach number was inconsistent with other altitudes. At altitudes above 15,000 feet, the maximum engine speed was limited by turbine-outlet temperature.

The specific fuel consumption (fig. 4(d)) was essentially constant for altitudes from 5000 to 45,000 feet at engine speeds above 7200 rpm and for altitudes from 15,000 to 45,000 feet at engine speeds above 5750 rpm. In the engine-speed range between 4500 to 6600 rpm, the highest specific fuel consumption occurred at an altitude of 5000 feet; at engine speeds above 6600 rpm, the highest specific fuel consumption occurred at an altitude of 50,000 feet. The data indicated no consistent altitude effect at engine speeds below 5750 rpm, probably because of large variations in component efficiencies in the low engine-speed range. The minimum specific fuel consumption of 1.05 pounds per hour per pound of net thrust was obtained at an engine speed of approximately 6400 rpm at altitudes from 15,000 to 45,000 feet. The specific fuel consumption at temperature-limited engine speed varied from 1.20 to 1.30 over the range of altitudes investigated.

The engine fuel-air ratio (fig. 4(e)) increased with altitude at engine speeds above 4500 rpm. Data obtained at lower engine speeds indicated no consistent altitude effect.

The exhaust-gas temperature (fig. 4(f)) decreased with an increase in altitude at low engine speeds and increased with altitude at high engine speeds. A change in altitude from 5000 to 25,000 feet resulted in a decrease in temperature-limited engine speed from 7880 to 7550 rpm. The trend of the data indicates that an increase in altitude beyond 25,000 feet would further reduce the maximum permissible engine speed. Inasmuch as maximum thrust is obtained at full engine speed (7900 rpm), and maximum exhaust-gas total temperature, the desirability of using a variable-area exhaust nozzle to permit operation at full engine speed at all altitudes is evident.

Effect of flight Mach number. - Performance data obtained at an altitude of 25,000 feet and flight Mach numbers of 0.21 to 0.97 are presented in figure 5 to show the effect of flight Mach number on net thrust, air flow, fuel flow, specific fuel consumption, fuel-air ratio, and exhaust-gas total temperature.

As the flight Mach number was raised, the net thrust decreased at engine speeds below 6800 rpm and increased at higher engine speeds for flight Mach numbers above 0.53 (fig. 5 (a)). An increase in Mach number from 0.21 to 0.53 at engine speeds above 7000 rpm had no appreciable effect on the net thrust. The engine air flow (fig. 5(b)) increased consistently with an increase in flight Mach number. As the flight Mach number was increased, the engine fuel consumption (fig. 5(c)) decreased at engine speeds below 6150 rpm and increased at higher engine speeds. At temperature-limited engine speed, the specific fuel consumption based on net thrust (fig. 5(d)) increased from 1.21 to 1.43 as the flight Mach number increased from 0.21 to 0.97. This variation of specific fuel consumption based on net thrust with flight Mach number increased at the low engine speeds. The minimum specific fuel consumption of 1.05 pounds per hour per pound of net thrust occurred at a flight Mach number of 0.21 and an engine speed of 1159 approximately 6400 rpm.

The engine fuel-air ratio (fig. 5(e)) decreased at all engine speeds as the flight Mach number was raised. The exhaust-gas total temperature (fig. 5(f)) was, in general, reduced by an increase in flight Mach number at all engine speeds except between 7000 and 7500 rpm, where a change in flight Mach number had no appreciable effect. Maximum engine speed was limited by exhaust-gas total temperature at flight Mach numbers below 0.72.

Generalized performance. - Altitude performance data for a flight Mach number of 0.21 have been generalized to standard sea-level conditions by use of the correction factors δ and θ (reference 1). In the development of this method of generalization, it was shown that these correction factors alone were insufficient to reduce the results completely to a single curve. The use of additional parameters, such as flight Mach number and Reynolds number, may be necessary for a complete generalized description of engine characteristics. Changes in flight Mach number or changes in component efficiency associated with changes in Reynolds number therefore lessen the possibility of reducing data obtained at various altitudes to a single curve.

Performance data obtained at a flight Mach number of 0.21 at altitudes from 5000 to 50,000 feet are presented in figure 6 to show the effect of altitude on the corrected values of net thrust, air flow, fuel flow, specific fuel consumption, fuel-air ratio, and exhaust-gas total temperature.

The variation of corrected net thrust with altitude was sufficiently small that data obtained at all altitudes from 5000 to 50,000 feet could be represented by a single curve (fig. 6(a)). The corrected engine air flow (fig. 6(b)) decreased as the altitude was increased at corrected engine speeds above 5400 rpm. For corrected engine speeds below 5400 rpm, the data appear to reduce to a single curve.

Generalized performance parameters depending on fuel consumption formed a single curve only near maximum engine speed and at altitudes below 35,000 feet. Above 35,000 feet and at reduced engine speeds, the corrected fuel consumption (fig. 6(c)) increased as the altitude was raised. Near maximum engine speed, the corrected specific fuel consumption (fig. 6(d)) formed a single curve for data obtained at altitudes below 35,000 feet; however, higher corrected specific fuel consumptions were obtained at altitudes of 45,000 and 50,000 feet. At low engine speeds the trend of the data with increasing altitude was inconsistent. The corrected engine fuel-air ratio (fig. 6(e)) and the corrected exhaust-gas temperature (fig. 6(f)) increased with altitude at all corrected engine speeds; however, the increase in corrected engine fuel-air ratio was insignificant at a corrected engine speed of 7900 rpm and altitudes up to 35,000 feet.

Generalization in terms of pumping characteristics. - If a turbojet engine is considered as a pump that increases the energy level of the working fluid as it passes through the engine, the thrust may be determined by an evaluation of the energy change. This change in available energy is determined by the change in total pressure and total temperature of the air flowing through the engine. In this method of generalization, as in the method previously discussed, changes in component efficiencies including the effects of Reynolds number lessen the possibility of generalizing the data obtained at various altitudes to a single curve.

The variation of engine total-temperature ratio with engine total-pressure ratio is shown in figure 7(a) for altitudes from 5000 to 50,000 feet at a flight Mach number of 0.21 and in figure 7(b) for flight Mach numbers from 0.21 to 0.97 at an altitude of 25,000 feet. As the altitude was increased, the engine-total-temperature ratio increased at all values of engine-total-pressure ratio. The data for the range of flight Mach numbers investigated at an altitude of 25,000 feet plotted as a single curve at all engine-pressure ratios above approximately 1.4. Similar data obtained over a range of flight Mach numbers at other altitudes also formed a single curve for each altitude at engine total-pressure ratios above approximately 1.4. From the data presented in figure 7, the total pressure at the exhaust-nozzle outlet can be determined for any flight Mach number and exhaust-gas temperature at altitudes between 5000 and 50,000 feet and engine-total-pressure ratios above approximately 1.4. The jet thrust can then be calculated by use of equation (8) or (9) presented in the appendix.

Engine Windmilling Characteristics

The engine windmilling speed is shown in figure 8 as a function of true airspeed for altitudes from 5000 to 45,000 feet. The engine windmilling speed was unaffected by changes in altitude in the range of airspeeds investigated.

The internal drag of a windmilling turbojet engine is of interest, particularly on multiengine airplanes when it may be desirable to cruise with one or more engines inoperative. The ratio of windmilling drag to net thrust at maximum permissible engine speed is shown in figure 9 as a function of true airspeed for an altitude of 25,000 feet. The internal drag of a windmilling engine varied from 2 percent of the available net thrust at a true airspeed of 200 miles per hour to 15 percent at a true airspeed of 650 miles per hour. The desirability of blocking the inlet of an inoperative engine is apparent.

SUMMARY OF RESULTS

The following results were obtained from an investigation of a J47 turbojet engine in the NACA Lewis altitude wind tunnel at simulated altitudes from 5000 to 50,000 feet and simulated flight Mach numbers from 0.21 to 0.97:

1. The correction factors commonly used to generalize turbojet-engine performance can be used to predict performance for only a limited range of altitudes and corrected engine speeds.

2. From the engine pumping characteristics, jet thrust could be predicted for any desired flight Mach number and exhaust-gas temperature at altitudes from 5000 to 50,000 feet and engine-pressure ratios above approximately 1.4.

3. The temperature-limited engine speed decreased with increasing altitude, which indicated the need for a variable-area exhaust nozzle.

4. In general, the exhaust-gas temperature was reduced at all engine speeds by an increase in flight Mach number.

5. The specific fuel consumption at temperature-limited engine speed and a flight Mach number of 0.21 varied from 1.20 to 1.30 pounds per hour per pound of net thrust over the range of altitudes investigated. Minimum specific fuel consumption of 1.05 pounds per hour per pound of net thrust was obtained at an engine speed of approximately 6400 rpm at altitudes from 15,000 to 45,000 feet.

6. As the flight Mach number was increased from 0.21 to 0.97 at temperature-limited engine speed, the specific fuel consumption increased from 1.21 to 1.43 pounds per hour per pound of net thrust. At low engine speeds the increase was much larger.

7. At an altitude of 25,000 feet, the internal drag of a windmilling engine varied from 2 percent of the available net thrust at a true airspeed of 200 miles per hour to 15 percent at a true airspeed of 650 miles per hour.

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APPENDIX - CALCULATIONS

Symbols

The following symbols were used in the calculations and on the figures:

A	cross-sectional area, sq ft
B	thrust scale reading, lb
C_j	jet-velocity coefficient, ratio of actual jet velocity or thrust to ideal velocity or thrust after expansion to free-stream static pressure
C_t	ratio of hot exhaust-nozzle area to cold exhaust-nozzle area (1.01 at 1570° R)
D	external drag of installation, lb
D_r	exhaust-nozzle tail-rake drag, lb
D_w	windmilling drag, lb
F_j	jet thrust, lb
F_n	net thrust, lb
f/a	fuel-air ratio
g	acceleration due to gravity, 32.2 ft/sec^2
M	flight Mach number
N	engine speed, rpm
P	total pressure, lb/sq ft absolute
p	static pressure, lb/sq ft absolute
R	gas constant, 53.3 ft-lb/(lb)(°R)
T	total temperature, °R
T_i	indicated temperature, °R

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t	static temperature, °R
V	velocity, ft/sec
W_a	air flow, lb/sec
W_f	fuel flow, lb/hr
W_f/F_n	specific fuel consumption based on net thrust, lb/(hr)(lb thrust)
γ	ratio of specific heats
δ	ratio of tunnel static pressure p_0 to absolute static pressure of NACA standard atmosphere at sea level
δ_a	ratio of tunnel static pressure p_0 to absolute static pressure of NACA standard atmosphere at desired altitude
θ	ratio of absolute equivalent ambient static temperature to absolute static temperature of NACA standard atmosphere at sea level
θ_a	ratio of absolute equivalent ambient static temperature to absolute static temperature of NACA standard atmosphere at desired altitude

Subscripts:

0	free-air stream
1	engine inlet
6	turbine outlet
7	1 inch upstream of exhaust-nozzle outlet
8	exhaust-nozzle outlet
e	equivalent
r	venturi throat rake in make-up air duct
s	scale
x	inlet duct at frictionless slip joint

Methods of Calculation

Flight Mach number. - Complete ram-pressure recovery at the engine inlet was assumed. The flight Mach number was then determined from the following expression:

$$M_0 = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{P_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \qquad (1)$$

Temperatures. - Total temperature was obtained from indicated temperature by the use of an experimentally determined thermocouple impact-recovery factor of 0.85 in the following equation:

$$T = \frac{T_i \left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}}}{1 + 0.85\left[\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \qquad (2)$$

Equivalent temperature. - Equivalent temperature was obtained from tunnel static pressure and engine-inlet total pressure and temperature.

$$t_e = \frac{T_1}{\left(\frac{P_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}}} \qquad (3)$$

Air flow. - Engine air flow was calculated from pressure and temperature measurements obtained at the engine inlet (station 1) by use of the equation

$$W_a = A_1 p_1 \sqrt{\frac{2\gamma g}{t_1 R(\gamma-1)}\left[\left(\frac{P_1}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \qquad (4)$$

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Air-flow values obtained from measurements in the venturi of the inlet-air duct and at the exhaust nozzle agreed within 3 percent with those obtained from measurements at the engine inlet.

Thrust. - The thrust of the installation was independently determined from balance-scale measurements and also from pressures and temperatures measured near the exhaust-nozzle outlet by means of a survey rake. Because of the inefficiency of the exhaust nozzle, the scale thrust is less than the rake thrust.

Jet thrust was determined from balance-scale measurements by the use of the following equation:

$$F_{j,s} = D + B + D_r + \frac{W_a V_x}{g} + A_x(p_x - p_0) \tag{5}$$

Net thrust is then given by the equation

$$F_{n,s} = F_{j,s} - \frac{W_a}{g} V_e \tag{6}$$

The last two terms of equation (5) represent the momentum and the pressure forces on the installation at the slip joint in the inlet-air duct. The drag of the installation was determined by runs with the engine inoperative and with a blocking plate installed in the inlet to prevent air flow through the engine.

The rake thrust, which is the ideal thrust available, is given by the following equation and values obtained at station 7, 1 inch upstream of the nozzle outlet:

$$F_{j,r} = \frac{2C_t A_7 p_7 \gamma_7}{\gamma_7 - 1}\left[\left(\frac{P_7}{p_7}\right)^{\frac{\gamma_8 - 1}{\gamma_8}} - 1\right] + C_t A_7 (p_7 - p_0) \tag{7}$$

Alternate thrust equation. - When the assumption is made that $P_7 = P_8$, an alternate equation for jet thrust is as follows:

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$$F_j = \frac{2\gamma_8}{\gamma_8-1} C_t A_8 p_8 \left[\left(\frac{P_8}{p_8}\right)^{\frac{\gamma_8-1}{\gamma_8}} -1\right] + A_8 C_t (p_8 - p_0) \qquad (8)$$

where

$$p_8 = \frac{P_8}{\left(\frac{\gamma_8+1}{2}\right)^{\frac{\gamma_8}{\gamma_8-1}}}$$

$\frac{P_8}{p_8} = 1.9$

$M_8 = 1.0$

and for supersonic jet velocities where

$$\frac{P_8}{p_0} > 1.9$$

For subsonic jet velocities where

$$\frac{P_8}{p_0} < 1.9$$

equation (8) reduces to

$$F_j = \frac{2\gamma_8 A_8 p_0 C_t}{\gamma_8-1} \left[\left(\frac{P_8}{p_0}\right)^{\frac{\gamma_8-1}{\gamma_8}} -1\right] \qquad (9)$$

$p_8 = p_0$

REFERENCE

1. Sanders, Newell D.: Performance Parameters for Jet-Propulsion Engines. NACA TN 1106, 1946.

TABLE I - ENGINE PERFORMANCE DATA

Run	Altitude (ft)	Ram-pressure ratio P_1/p_0	Flight Mach number M	Tunnel static pressure p_0, (lb/sq ft abs.)	Equivalent ambient temperature, t_e, (°R)	Engine speed, N (rpm)	Compressor-inlet indicated temperature $T_{i,1'}$ (°R)	Jet thrust, F_j (lb)	Net thrust, F_n (lb)	Engine-inlet air flow $W_{a,1'}$ (lb/sec)	Fuel flow, W_f (lb/hr)	Specific fuel consumption based on net thrust W_f/F_n, (lb/(hr)(lb thrust))	Fuel-air ratio f/a	Exhaust-gas total temperature, T_7, (°R)	Turbine-outlet total pressure, P_8, (lb/sq ft abs.)	Corrected engine speed $N/\sqrt{\theta}$, (rpm)	Corrected net thrust F_n/δ, (lb)	Corrected engine-inlet air flow, $W_{a,1}\sqrt{\theta}/\delta$ (lb/sec)	Corrected fuel consumption, $W_f/(\delta\sqrt{\theta})$ (lb/hr)	Corrected specific fuel consumption based on net thrust, $W_f/(F_n\sqrt{\theta})$ (lb/(hr)(lb thrust))	Corrected fuel-air ratio, $(f/a)/\theta$	Corrected exhaust-gas total temperature, T_7/θ, (°R)	Engine total-pressure ratio, P_7/P_1	Engine total-temperature ratio, T_7/T_1
1	5,000	1.038	0.230	1740	507	7895	509	4860	4237	81.08	5300	1.251	0.0182	1740	3466	7990	5160	97.42	6623	1.265	0.0186	1780	1.865	3.398
2	5,000	1.037	.225	1756	509	7692	511	4593	3957	81.07	4800	1.213	.0164	1631	3352	7789	4770	96.72	5842	1.225	.0167	1665	1.790	3.173
3	5,000	1.039	.230	1740	508	7500	510	4305	3660	80.28	4390	1.198	.0152	1542	3247	7598	4465	96.37	5408	1.215	.0156	1583	1.745	3.012
4	5,000	1.036	.220	1742	508	6993	511	3850	3055	76.94	3550	1.162	.0128	1396	2984	7070	3720	92.46	4359	1.175	.0130	1426	1.605	2.721
5	5,000	1.034	.215	1742	507	6459	511	2846	2318	70.23	2710	1.168	.0107	1268	2679	6537	2818	84.32	3333	1.183	.0109	1297	1.454	2.477
6	5,000	1.033	.210	1744	506	5944	510	2085	1615	63.66	2060	1.275	.0090	1170	2403	6021	1962	76.23	2532	1.292	.0092	1200	1.314	2.290
7	5,000	1.033	.210	1740	505	5024	509	1172	817	48.08	1350	1.654	.0078	1096	2083	5094	994	57.62	1665	1.675	.0079	1127	1.149	2.149
8	5,000	1.034	.215	1749	504	4091	509	669	413	34.21	1050	2.542	.0085	1125	1924	4152	499	40.78	1289	2.582	.0087	1160	1.059	2.210
9	5,000	1.032	.210	1745	504	3147	509	312	140	23.73	820	5.857	.0096	1167	1832	3194	169	28.36	1009	5.940	.0098	1202	1.017	2.293
10	5,000	1.032	.210	1738	504	2046	509	129	10	16.42	474	-----	.0080	1134	1769	2077	12	19.69	585	48.1	.0082	1168	.987	2.228
11	15,000	1.034	.215	1188	478	6993	480	2735	2323	56.41	2550	1.097	.0126	1386	2102	7287	4137	96.42	4733	1.142	.0137	1506	1.664	2.870
12	15,000	1.030	.205	1188	479	6459	481	2219	1863	51.80	2020	1.085	.0108	1254	1896	6724	3320	88.62	3745	1.130	.0117	1358	1.507	2.596
13	15,000	1.030	.205	1188	475	5944	478	1694	1375	46.67	1550	1.127	.0092	1145	1707	6211	2450	79.54	2885	1.178	.0100	1253	1.367	2.390
14	15,000	1.030	.205	1186	471	5024	475	1000	755	36.00	980	1.297	.0076	1034	1454	5275	1344	61.17	1836	1.361	.0083	1138	1.180	2.177
15	15,000	1.028	.195	1186	471	4091	475	538	378	24.58	768	2.043	.0087	1060	1320	4296	670	41.76	1438	2.145	.0095	1167	1.076	2.232
16	15,000	1.031	.205	1190	470	3147	474	304	169	19.42	605	3.580	.0087	1119	1261	3307	300	32.85	1131	3.768	.0095	1235	1.024	2.361
17	15,000	1.028	.195	1188	468	2046	472	157	100	8.58	371	3.675	.0120	1105	1213	2154	179	14.51	696	3.870	.0133	1225	.992	2.341
18	15,000	1.204	.525	1186	474	7895	498	4016	2936	62.37	4130	1.407	.0184	1754	2685	----	----	-----	----	------	------	----	1.820	3.508
19	15,000	1.210	.530	1186	477	7692	502	3912	2776	64.50	3730	1.344	.0161	1614	2625	----	----	-----	----	------	------	----	1.781	3.202
20	15,000	1.211	.530	1186	480	7500	505	3698	2563	64.09	3395	1.324	.0147	1544	2549	----	----	-----	----	------	------	----	1.719	3.045
21	15,000	1.205	.525	1190	480	6993	504	3210	2132	61.72	2720	1.275	.0122	1362	2334	----	----	-----	----	------	------	----	1.577	2.692
22	15,000	1.203	.520	1188	482	6459	506	2430	1441	56.77	1990	1.380	.0097	1200	2089	----	----	-----	----	------	------	----	1.383	2.362
23	15,000	1.205	.520	1190	480	5944	505	1755	869	50.82	1380	1.590	.0075	1058	1765	----	----	-----	----	------	------	----	1.212	2.091
24	15,000	1.204	.525	1185	479	5024	504	904	227	38.87	770	3.392	.0055	914	1458	----	----	-----	----	------	------	----	1.015	1.810
25	15,000	1.203	.520	1190	481	4091	506	419	-68	27.95	549	-----	.0055	880	1340	----	----	-----	----	------	------	----	.929	1.736
26	15,000	1.203	.520	1190	478	3147	503	197	-185	21.99	361	-----	.0046	801	1256	----	----	-----	----	------	------	----	.876	1.569
27	25,000	1.037	.225	777	447	7692	450	2409	2127	38.38	2610	1.228	.0189	1763	1661	8284	5790	97.04	7654	1.323	.0218	2067	1.990	3.945
28	25,000	1.037	.225	774	450	7500	453	2175	1895	38.09	2200	1.162	.0161	1580	1549	8055	5181	96.78	6460	1.247	.0187	1820	1.872	3.475
29	25,000	1.036	.220	777	451	6993	454	1876	1603	37.39	1780	1.111	.0132	1388	1433	7503	4360	94.89	5201	1.191	.0152	1598	1.735	3.044
30	25,000	1.033	.210	779	451	6459	453	1565	1318	35.39	1420	1.077	.0111	1244	1310	6931	3580	89.58	4139	1.156	.0128	1430	1.589	2.734
31	25,000	1.033	.210	778	452	5944	455	1176	955	31.96	1070	1.120	.0093	1121	1155	6366	2597	81.17	3115	1.200	.0107	1287	1.412	2.458
32	25,000	1.031	.205	778	451	5024	455	598	431	24.64	702	1.630	.0079	1011	972	5591	1173	62.46	2048	1.747	.0091	1163	1.203	2.222
33	25,000	1.030	.205	777	452	4091	455	306	184	18.10	560	3.043	.0086	1034	870	4381	501	46.02	1635	3.259	.0099	1188	1.082	2.268
34	25,000	1.030	.205	774	452	3147	456	159	77	12.24	440	5.710	.0100	1095	815	3570	210	31.25	1296	6.120	.0115	1258	1.022	2.401
35	25,000	1.030	.206	774	451	2046	456	80	22	8.70	366	-----	.0117	1152	790	2195	59	22.17	1074	17.89	.0136	1323	.996	2.532
36	25,000	1.207	.525	781	444	7895	466	3017	2270	44.26	3025	1.332	.0190	1781	1900	----	----	-----	----	------	------	----	1.952	3.806
37	25,000	1.209	.530	774	441	7692	463	2884	2136	44.25	2725	1.277	.0171	1661	1834	----	----	-----	----	------	------	----	1.899	3.564
38	25,000	1.211	.530	781	432	7500	464	2771	2012	45.17	2530	1.267	.0157	1549	1811	----	----	-----	----	------	------	----	1.859	3.397
39	25,000	1.213	.535	774	431	6993	464	2470	1724	44.24	2030	1.178	.0127	1359	1658	----	----	-----	----	------	------	----	1.715	2.980

40	25,000	1.211	0.530	778	434	6459	456	1973	1869	41.79	1590	1.263	0.0106	1200	1469	----	----	-----	----	------	------	----	1.516	2.620
41	25,000	1.208	.530	785	436	5944	458	1415	778	38.14	1139	1.467	.0085	1045	1269	----	----	-----	----	------	------	----	1.312	2.372
42	25,000	1.203	.520	778	442	5024	466	767	299	28.06	600	2.005	.0059	900	999	----	----	-----	----	------	------	----	1.056	1.931
43	25,000	1.202	.520	781	442	4091	465	341	-9	21.02	425	------	.0056	831	885	----	----	-----	----	------	------	----	.938	1.783
44	25,000	1.204	.525	781	441	3147	465	150	-101	15.02	306	------	.0057	785	833	----	----	-----	----	------	------	----	.884	1.688
45	25,000	1.199	.515	778	440	2727	463	96	-130	13.71	266	------	.0054	753	816	----	----	-----	----	------	------	----	.872	1.626
46	25,000	1.412	.720	774	425	7895	467	3692	2520	51.82	3410	1.353	.0183	1763	2199	----	----	-----	----	------	------	----	1.946	3.759
47	25,000	1.403	.715	776	431	7692	472	3545	2400	50.79	3150	1.313	.0172	1673	2133	----	----	-----	----	------	------	----	1.894	3.522
48	25,000	1.403	.715	781	434	7500	475	3274	2125	50.75	2750	1.293	.0151	1530	2022	----	----	-----	----	------	------	----	1.795	3.201
49	25,000	1.413	.720	780	433	6993	476	2927	1777	50.34	2220	1.249	.0123	1358	1867	----	----	-----	----	------	------	----	1.642	2.841
50	25,000	1.410	.720	783	432	6459	475	2357	1274	47.59	1660	1.303	.0097	1174	1651	----	----	-----	----	------	------	----	1.432	2.461
51	25,000	1.415	.725	781	435	5944	479	1649	656	45.26	1020	1.556	.0065	962	1350	----	----	-----	----	------	------	----	1.190	2.046
52	25,000	1.406	.720	781	433	5084	476	798	50	32.96	469	9.380	.0040	780	1036	----	----	-----	----	------	------	----	.929	1.635
53	25,000	1.603	.850	778	429	7895	488	4196	2647	57.76	3660	1.583	.0176	1701	2411	----	----	-----	----	------	------	----	1.871	3.464
54	25,000	1.611	.855	774	435	7500	496	3752	2217	56.50	3050	1.376	.0150	1646	2237	----	----	-----	----	------	------	----	1.740	3.104
55	25,000	1.611	.855	781	437	6993	499	3257	1785	54.06	2420	1.357	.0124	1359	2048	----	----	-----	----	------	------	----	1.577	2.713
56	25,000	1.609	.850	781	437	6459	499	2550	1144	50.99	1680	1.469	.0092	1157	1744	----	----	-----	----	------	------	----	1.382	2.309
57	25,000	1.603	.850	781	436	5944	497	1751	526	45.33	970	1.846	.0059	941	1416	----	----	-----	----	------	------	----	1.109	1.890
58	25,000	1.612	.855	781	438	5084	502	800	-172	35.63	346	------	.0027	717	1059	----	----	-----	----	------	------	----	.827	1.428
59	25,000	1.857	.982	746	421	7895	499	4795	2643	65.46	4000	1.406	.0175	1705	2659	----	----	-----	----	------	------	----	1.860	3.396
60	25,000	1.817	.965	778	431	7692	509	4636	2674	63.95	3730	1.394	.0162	1629	2598	----	----	-----	----	------	------	----	1.784	3.188
61	25,000	1.839	.975	774	431	7500	510	4448	2479	63.83	3400	1.372	.0146	1554	2532	----	----	-----	----	------	------	----	1.724	3.029
62	25,000	1.840	.975	774	432	6993	512	3876	1988	61.07	2640	1.387	.0120	1365	2292	----	----	-----	----	------	------	----	1.551	2.656
63	35,000	1.052	.210	496	440	7692	442	1526	1360	24.42	1719	1.264	.0196	1814	1063	8354	5810	95.93	7964	1.372	0.0231	2140	2.008	4.086
64	35,000	1.054	.215	495	441	7500	443	1429	1258	24.43	1505	1.194	.0171	1681	1010	8138	5399	96.64	7008	1.295	.0202	1920	1.916	3.778
65	35,000	1.036	.220	496	441	6993	444	1250	1076	24.05	1184	1.100	.0137	1428	929	7587	4590	94.56	5420	1.194	.0161	1681	1.749	3.202
66	35,000	1.032	.210	496	441	6459	443	1014	859	22.87	944	1.098	.0115	1273	846	7008	3663	89.92	4369	1.192	.0135	1498	1.606	2.861
67	35,000	1.030	.205	493	441	5944	444	734	598	20.57	723	1.210	.0098	1138	740	6449	2570	81.37	3367	1.312	.0115	1341	1.425	2.557
68	35,000	1.050	.205	494	441	5024	445	440	336	15.99	497	1.485	.0086	1018	617	5451	1437	63.12	2310	1.610	.0101	1198	1.194	2.288
69	35,000	1.028	.195	497	443	4091	445	225	153	11.23	381	2.490	.0094	1082	563	4431	655	44.15	1757	2.695	.0110	1245	1.094	2.381
70	35,000	1.204	.525	494	425	7692	446	1863	1395	28.56	1870	1.341	.0182	1723	1199	----	----	-----	----	------	------	----	1.953	3.846
71	35,000	1.211	.530	493	424	7500	446	1774	1297	28.66	1690	1.302	.0164	1598	1159	----	----	-----	----	------	------	----	1.891	3.567
72	35,000	1.208	.530	495	425	6993	447	1511	1043	28.26	1300	1.246	.0128	1386	1066	----	----	-----	----	------	------	----	1.706	3.087
73	35,000	1.200	.520	496	424	6459	446	1251	826	26.86	1000	1.212	.0106	1213	945	----	----	-----	----	------	------	----	1.559	2.714
74	35,000	1.202	.520	496	425	5944	446	919	522	24.32	760	1.457	.0087	1051	817	----	----	-----	----	------	------	----	1.337	2.346
75	35,000	1.198	.515	495	424	5024	446	458	154	18.82	430	2.792	.0063	876	644	----	----	-----	----	------	------	----	1.067	1.964
76	35,000	1.409	.720	494	406	7800	446	2418	1675	33.74	2295	1.371	.0189	1784	1427	----	----	-----	----	------	------	----	1.990	3.978
77	35,000	1.411	.720	494	405	7692	445	2364	1507	33.83	2165	1.347	.0178	1724	1405	----	----	-----	----	------	------	----	1.950	3.857
78	35,000	1.411	.720	496	404	7500	444	2220	1468	34.14	1950	1.328	.0159	1579	1350	----	----	-----	----	------	------	----	1.870	3.640
79	35,000	1.413	.720	496	405	6993	445	1987	1243	33.76	1550	1.248	.0128	1373	1236	----	----	-----	----	------	------	----	1.710	3.085
80	35,000	1.407	.720	496	403	6459	443	1623	918	32.19	1175	1.278	.0101	1197	1101	----	----	-----	----	------	------	----	1.530	2.696
81	35,000	1.411	.720	494	401	5944	440	1213	675	29.09	820	1.426	.0078	998	924	----	----	-----	----	------	------	----	1.294	2.258
82	35,000	1.405	.715	496	401	6455	441	820	251	26.10	544	2.165	.0058	849	772	----	----	-----	----	------	------	----	1.090	1.921
83	45,000	1.037	.225	298	437	7500	440	924	817	14.72	1030	1.261	.0194	1795	637	8175	5810	95.90	7972	1.375	.0250	2130	1.994	4.057
84	45,000	1.039	.200	308	442	6993	444	795	701	14.45	788	1.124	.0152	1510	582	7580	4810	91.45	5869	1.218	.0178	1775	1.773	3.386
85	45,000	1.037	.225	297	438	6459	442	623	525	13.78	615	1.176	.0124	1316	510	7034	3730	90.16	4772	1.280	.0147	1561	1.604	2.971
86	45,000	1.033	.210	306	441	5944	443	472	386	12.42	474	1.228	.0106	1176	466	6449	2668	79.15	3557	1.334	.0125	1387	1.440	2.643
87	45,000	1.030	.205	303	440	5024	444	250	185	9.81	328	1.762	.0092	1076	378	5456	1292	65.06	2472	1.919	.0109	1270	1.190	2.423
88	45,000	1.206	.528	301	422	7692	443	1180	896	17.28	1285	1.367	.0197	1830	760	----	----	-----	----	------	------	----	2.000	4.112
89	45,000	1.209	.530	301	422	7500	444	1105	811	17.77	1093	1.347	.0171	1710	713	----	----	-----	----	------	------	----	1.893	3.634
90	45,000	1.198	.515	303	422	6993	442	965	696	16.67	847	1.217	.0141	1456	648	----	----	-----	----	------	------	----	1.725	3.279
91	45,000	1.204	.525	304	420	6459	441	774	510	16.18	655	1.284	.0112	1253	578	----	----	-----	----	------	------	----	1.527	2.828
92	45,000	1.205	.525	303	420	5944	442	560	317	14.67	497	1.568	.0085	1067	502	----	----	-----	----	------	------	----	1.348	2.454
93	45,000	1.203	.520	296	420	5024	442	318	133	11.35	271	2.055	.0066	915	388	----	----	-----	----	------	------	----	1.070	2.055
94	50,000	1.027	.190	225	440	7500	441	668	600	10.97	773	1.289	.0196	1812	469	8145	5630	94.99	7894	1.401	.0251	2140	1.974	4.090
95	50,000	1.025	.185	236	440	6993	441	580	514	11.00	637	1.240	.0161	1554	446	7594	4600	90.82	6804	1.350	.0190	1835	1.785	3.508
96	50,000	1.025	.185	238	438	6459	440	475	413	10.54	493	1.193	.0132	1346	404	7034	3650	84.42	4774	1.308	.0156	1595	1.606	3.062
97	50,000	1.025	.185	239	437	5944	439	391	333	9.62	416	1.249	.0120	1221	365	6479	2950	78.14	4015	1.362	.0143	1453	1.453	2.775

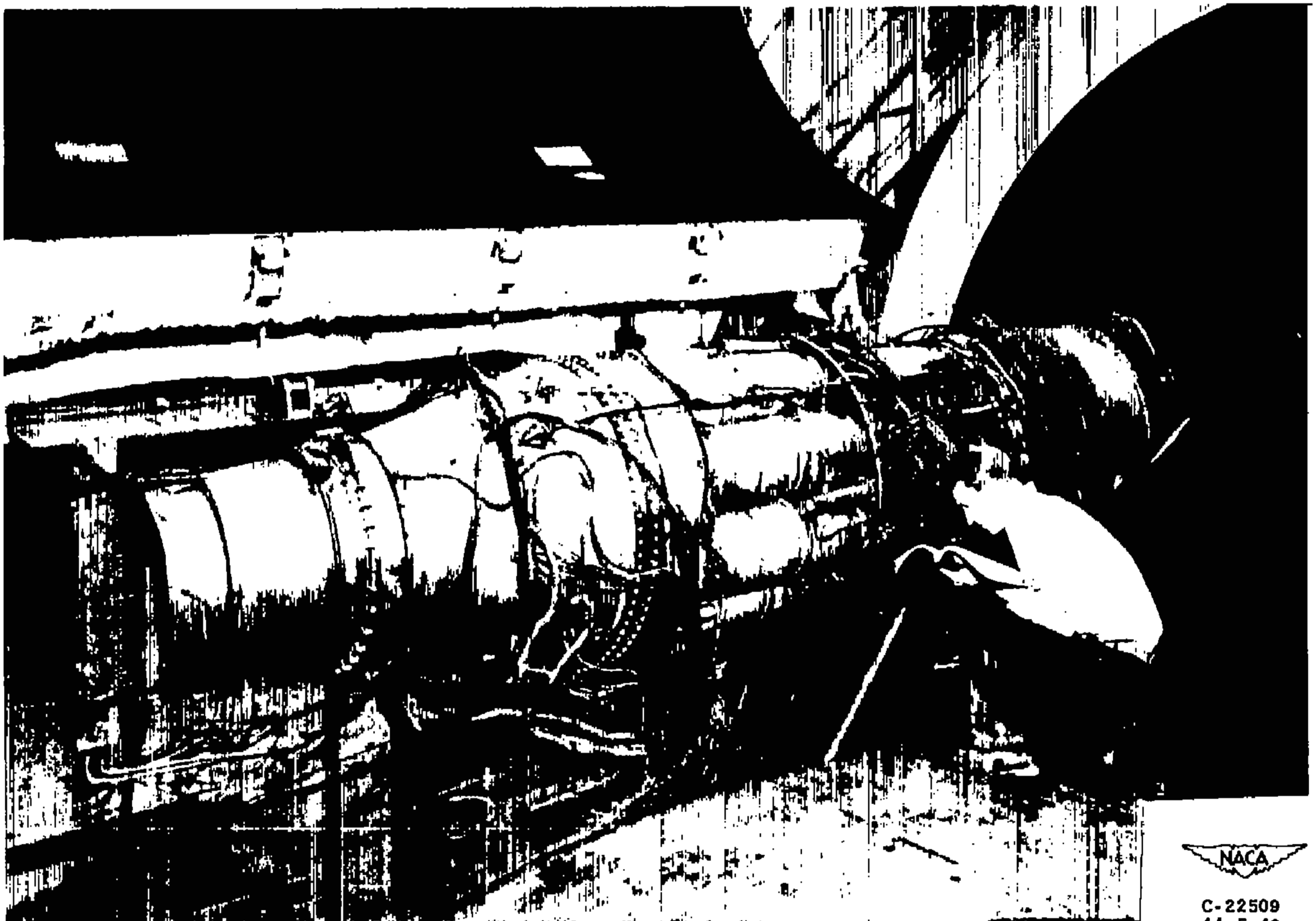

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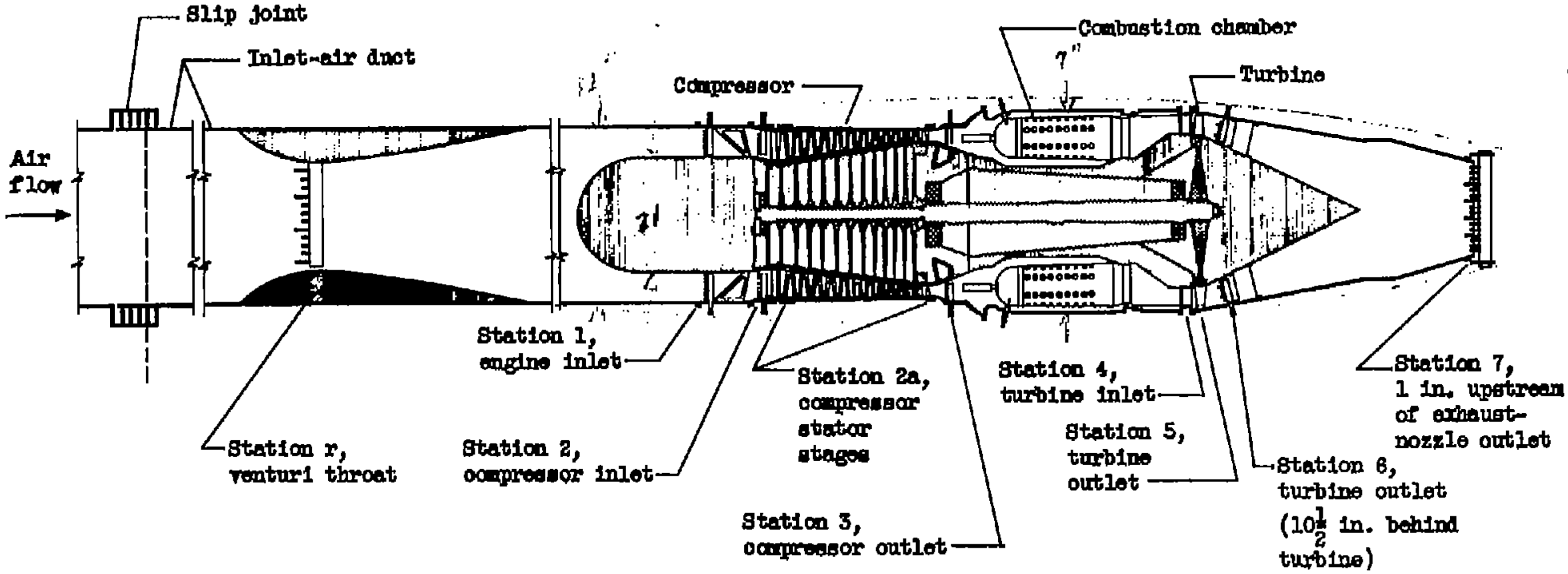
Figure 1. - View of J47 turbojet engine installed in test section of altitude wind tunnel.



Station	Total pressure tubes	Static-pressure tubes	Wall static-pressure orifices	Thermo-couples
r	12	4	4	6
1	40	4	0	8
2	24	0	4	0
2a	0	0	13	0
3	20	0	4	6
4	5	0	0	0
5	0	0	0	8
6	30	0	2	33
7	18	5	4	14

Figure 2. - Cross section of turbojet-engine installation showing sections at which instrumentation was installed.

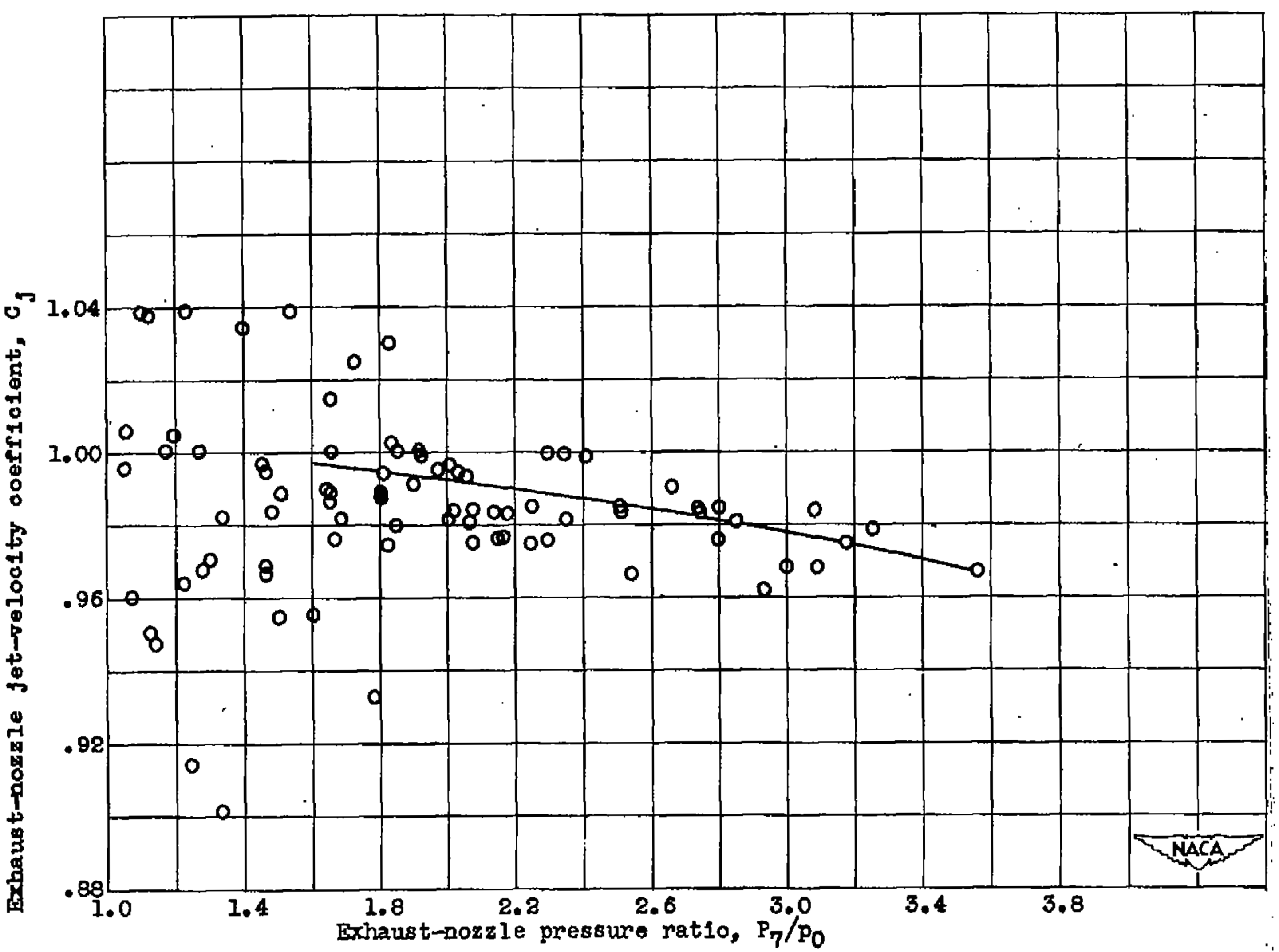
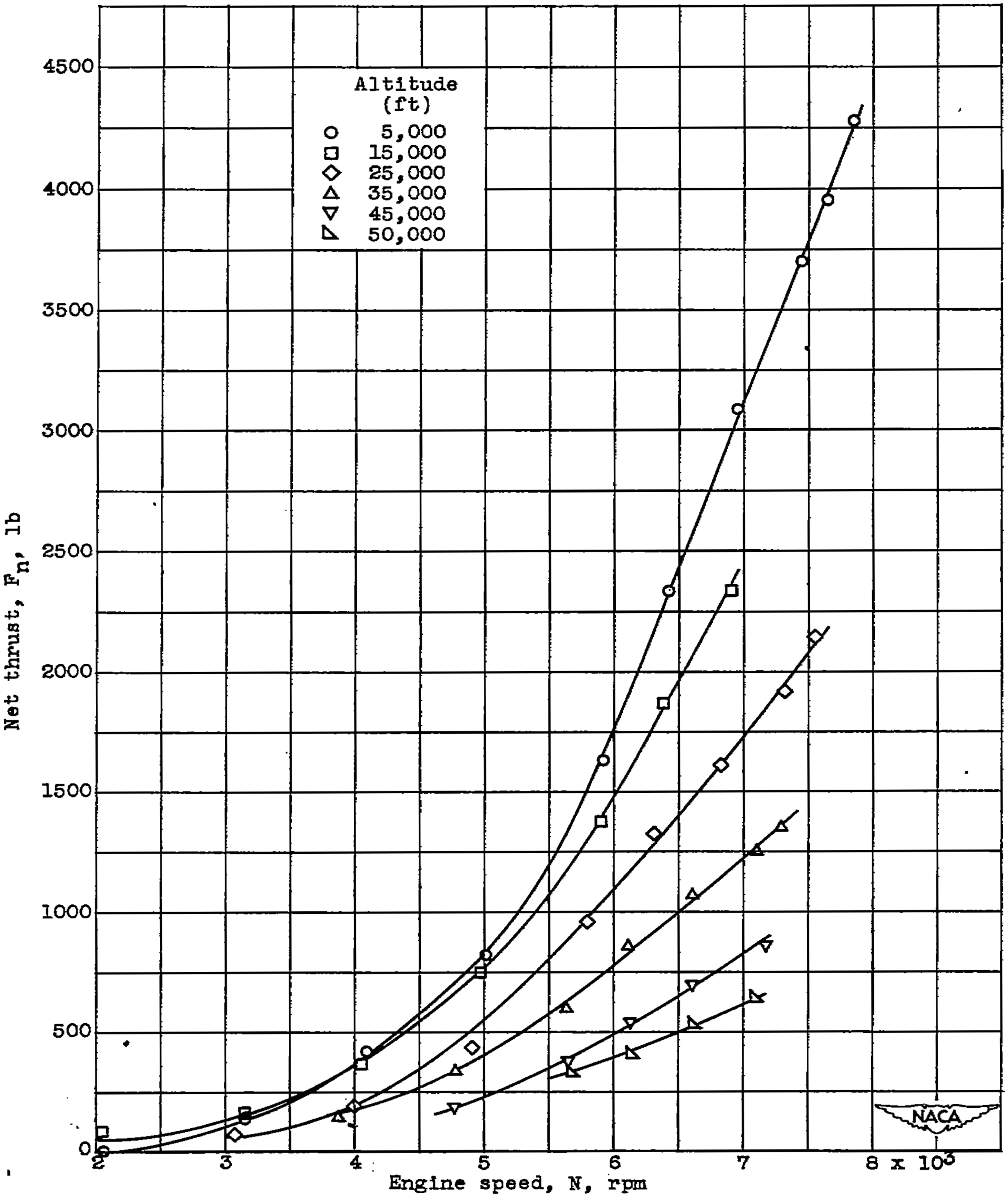
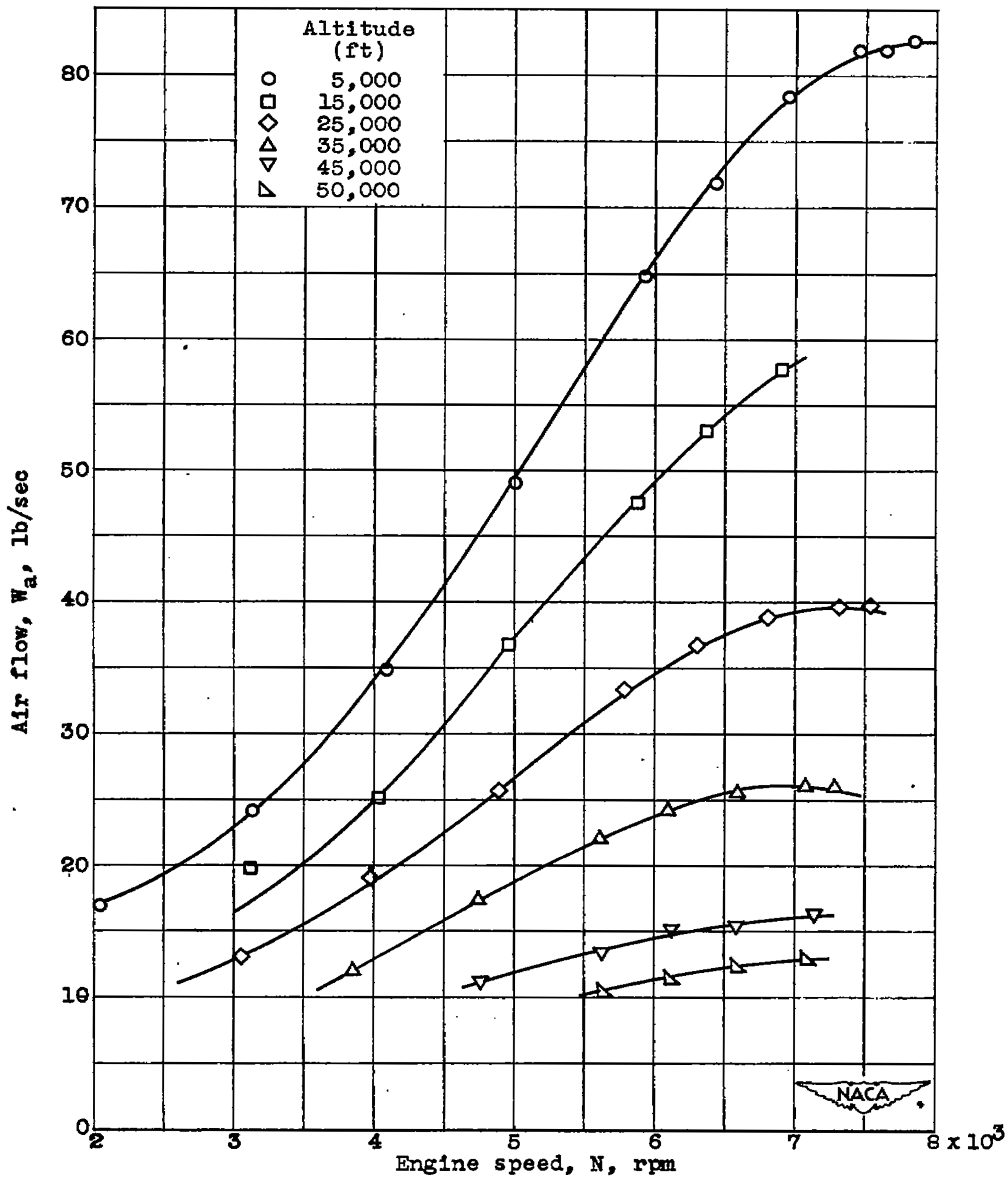


Figure 3. - Variation of exhaust-nozzle jet-velocity coefficient with exhaust-nozzle pressure ratio.



(a) Net thrust.

Figure 4. - Effect of altitude on variation of engine performance with engine speed at flight Mach number of 0.21.



(b) Air flow.

Figure 4. - Continued. Effect of altitude on variation of engine performance with engine speed at flight Mach number of 0.21.

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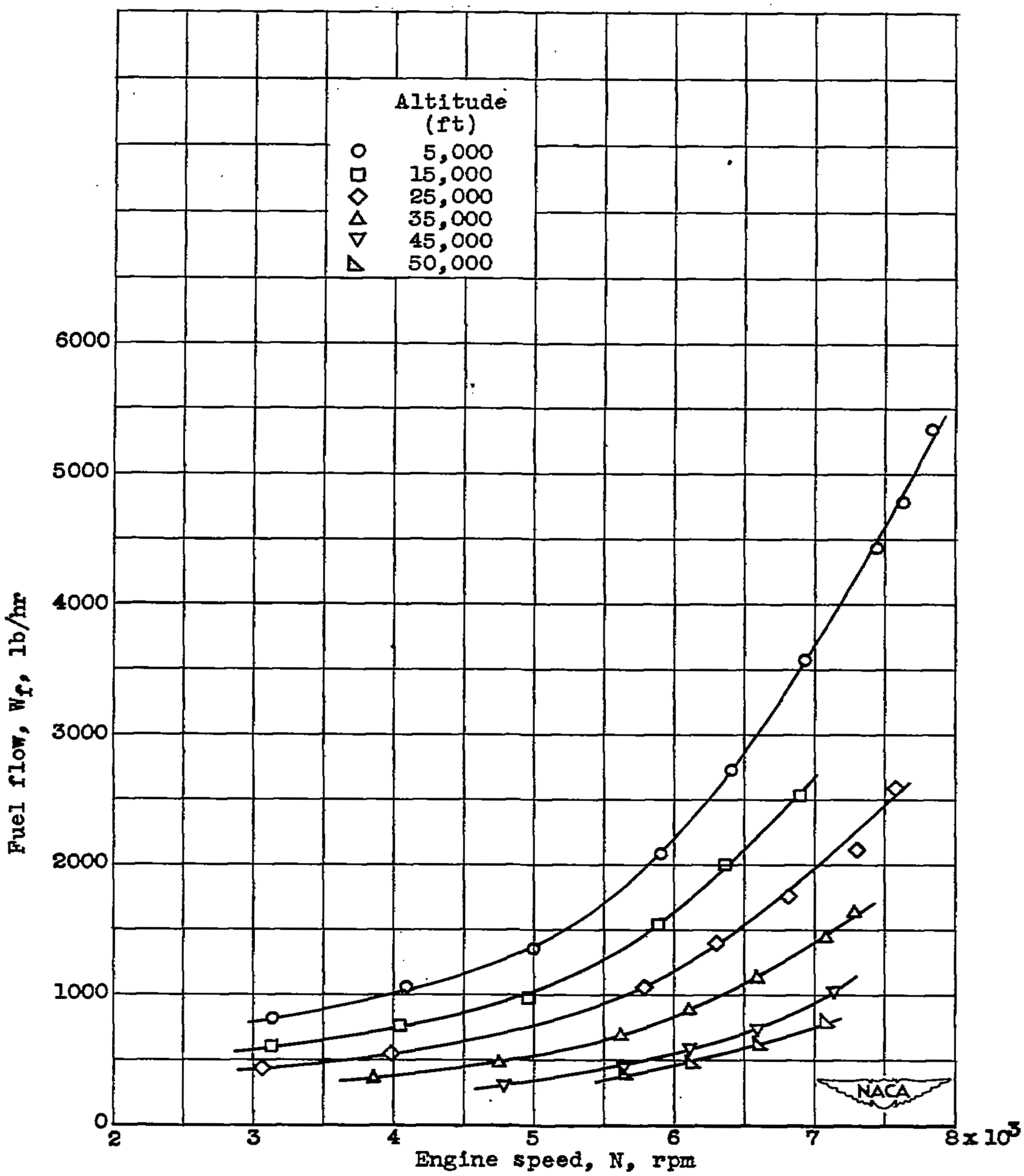
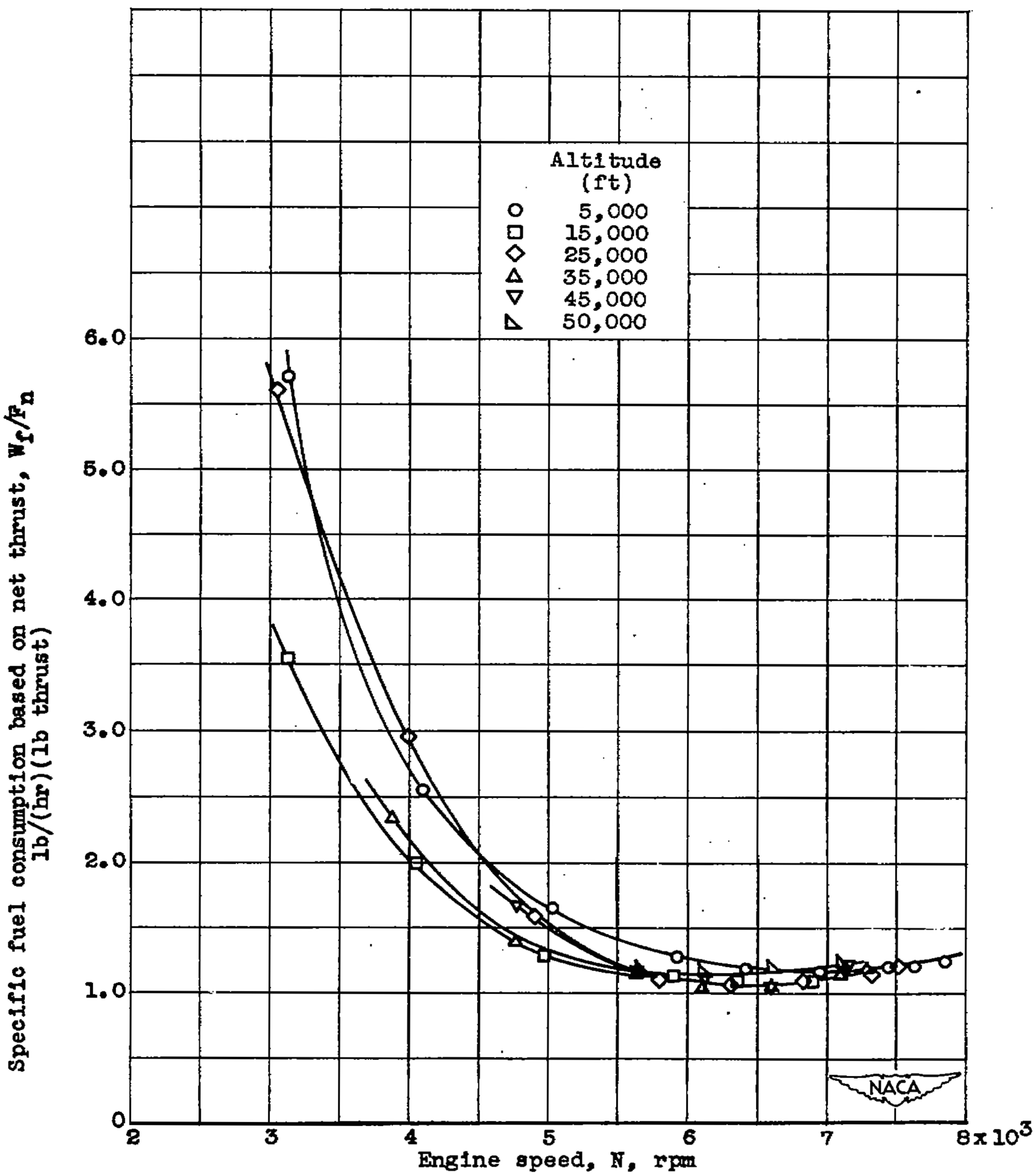


(c) Fuel flow.

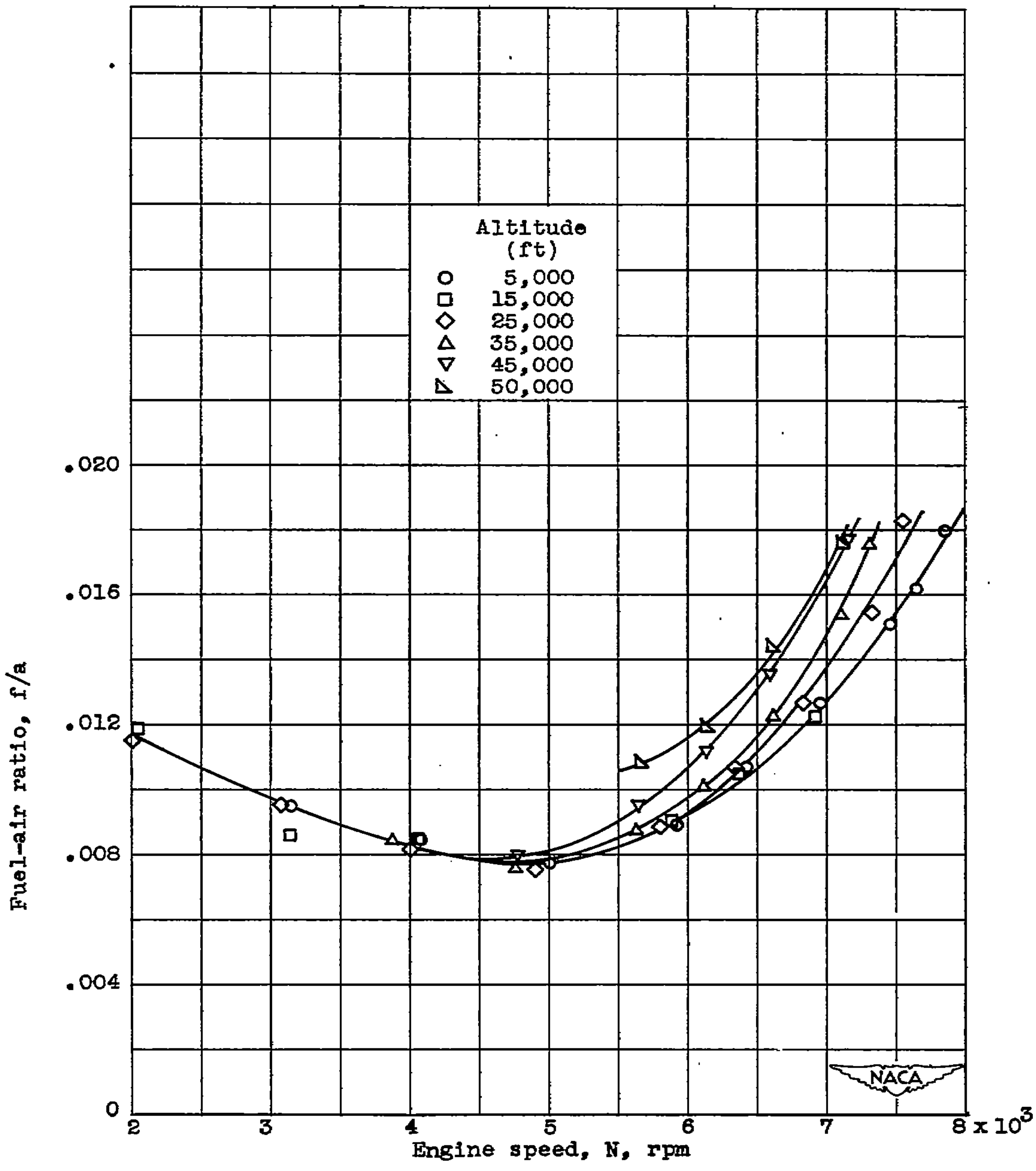
Figure 4. - Continued. Effect of altitude on variation of engine performance with engine speed at flight Mach number of 0.21.



(d) Specific fuel consumption

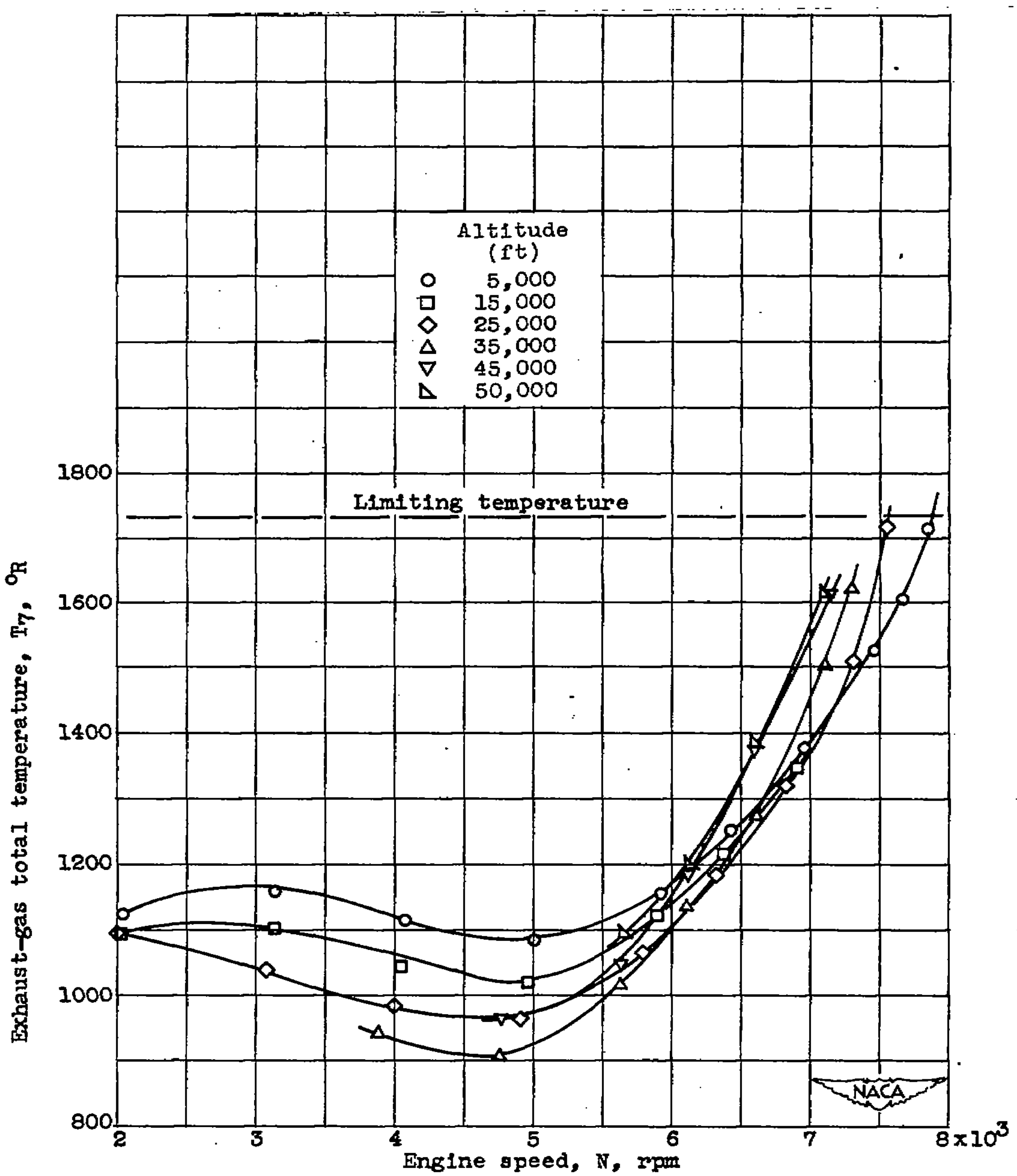
Figure 4. - Continued. Effect of altitude on variation of engine performance with engine speed at flight Mach number of 0.21.

1159



(e) Fuel-air ratio.

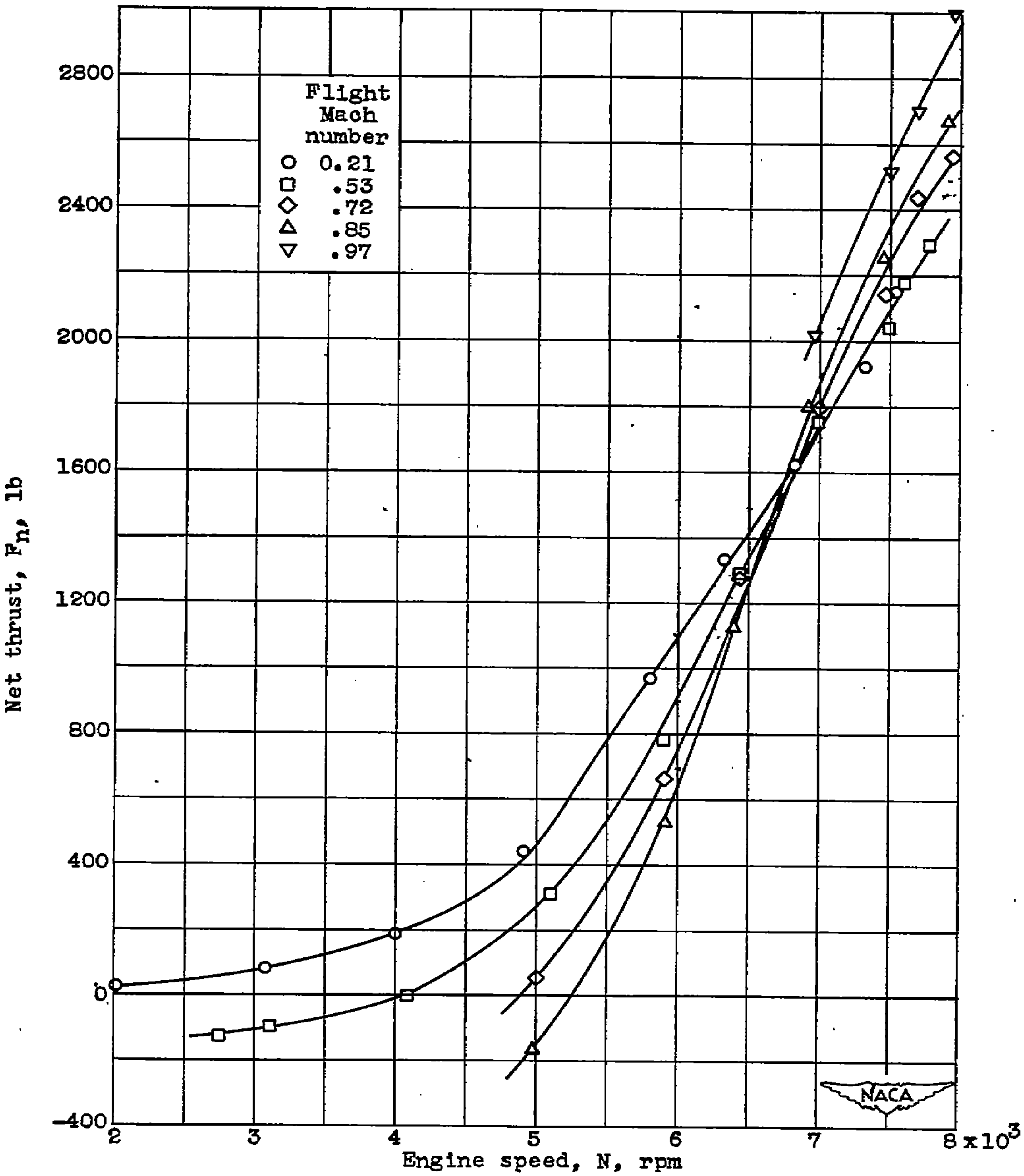
Figure 4. - Continued. Effect of altitude on variation of engine performance with engine speed at flight Mach number of 0.21.



(f) Exhaust-gas total temperature.

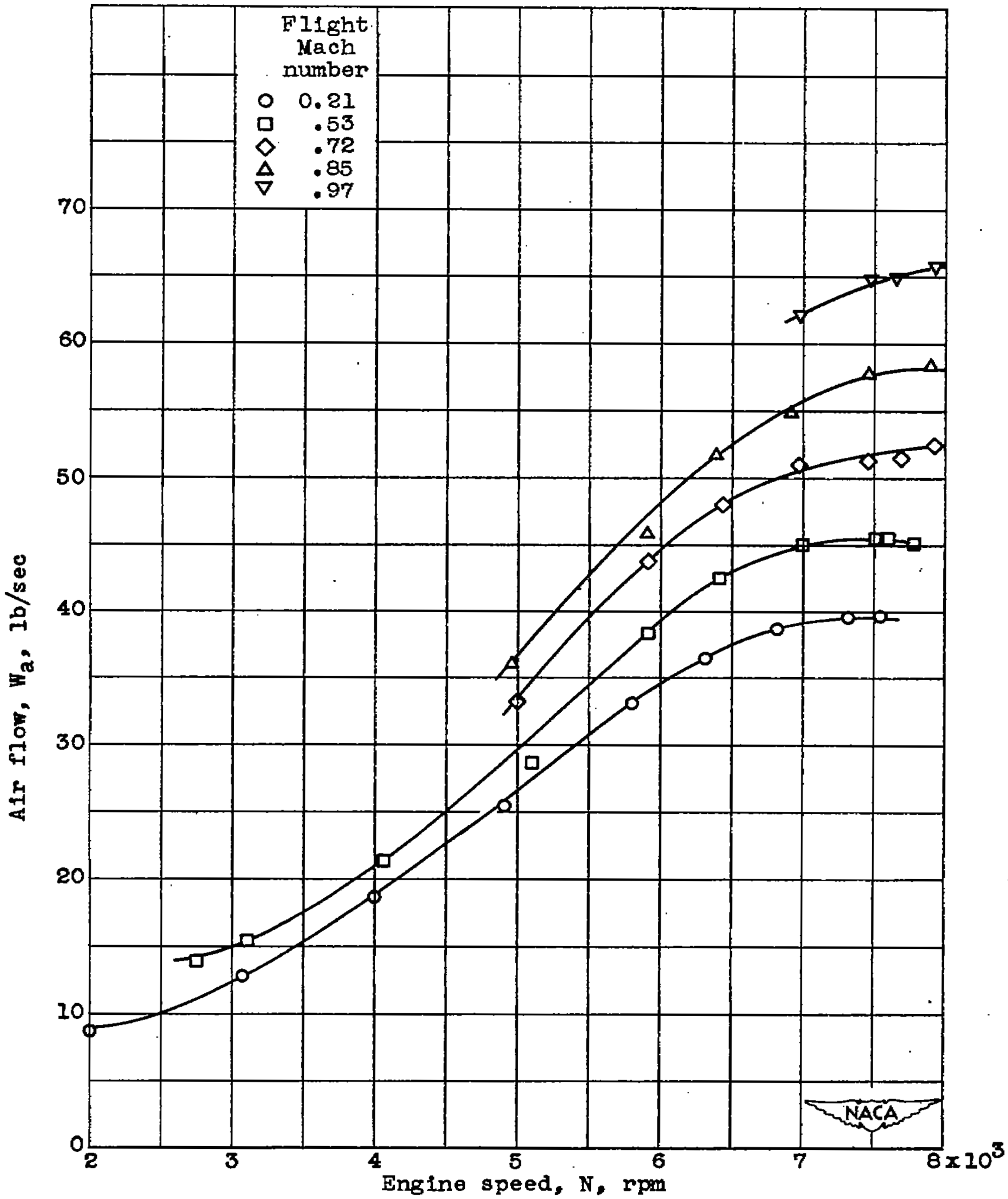
Figure 4. - Concluded. Effect of altitude on variation of engine performance with engine speed at flight Mach number of 0.21.

1159



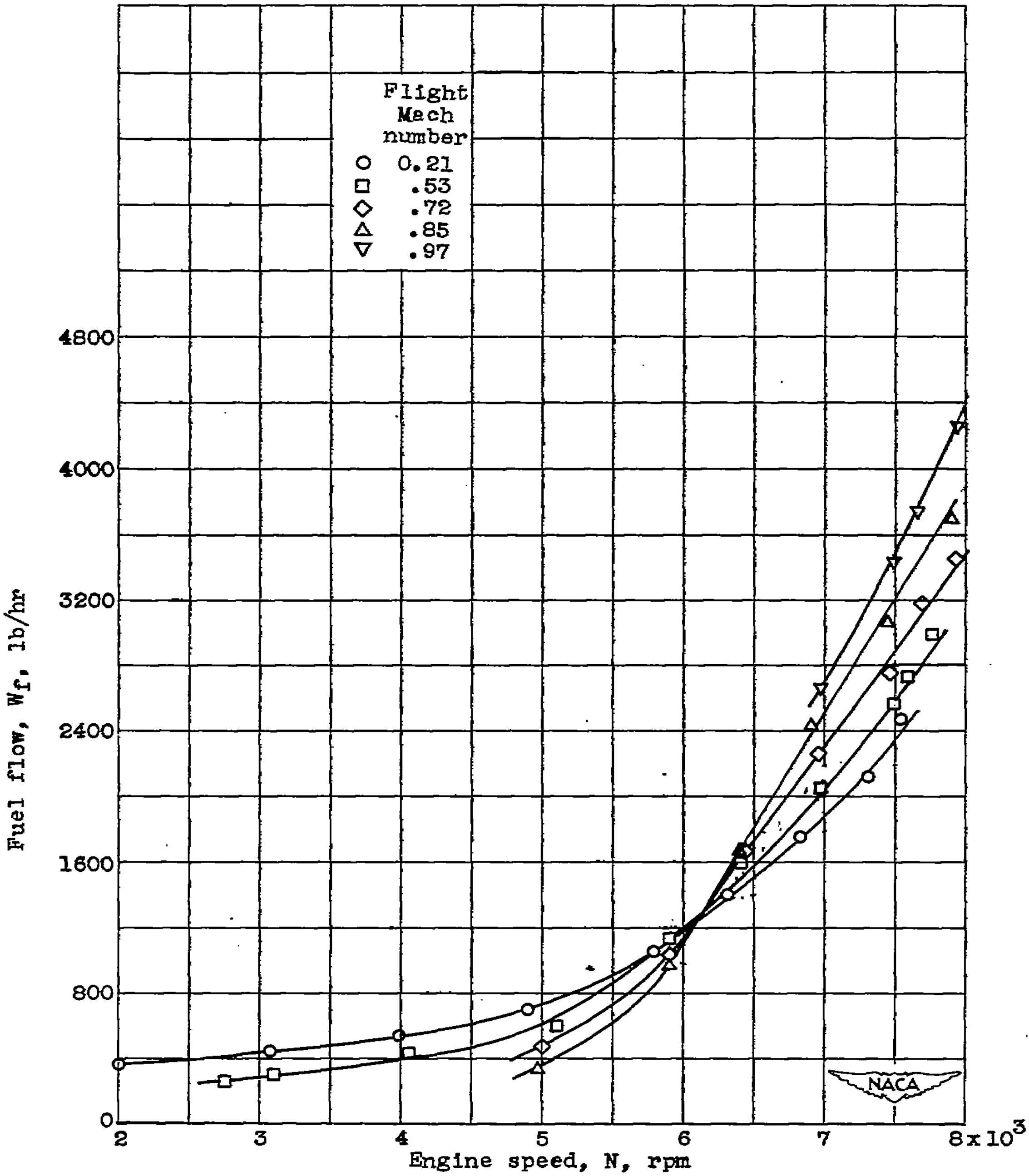
(a) Net thrust.

Figure 5. - Effect of flight Mach number on variation of engine performance with engine speed at altitude of 25,000 feet.



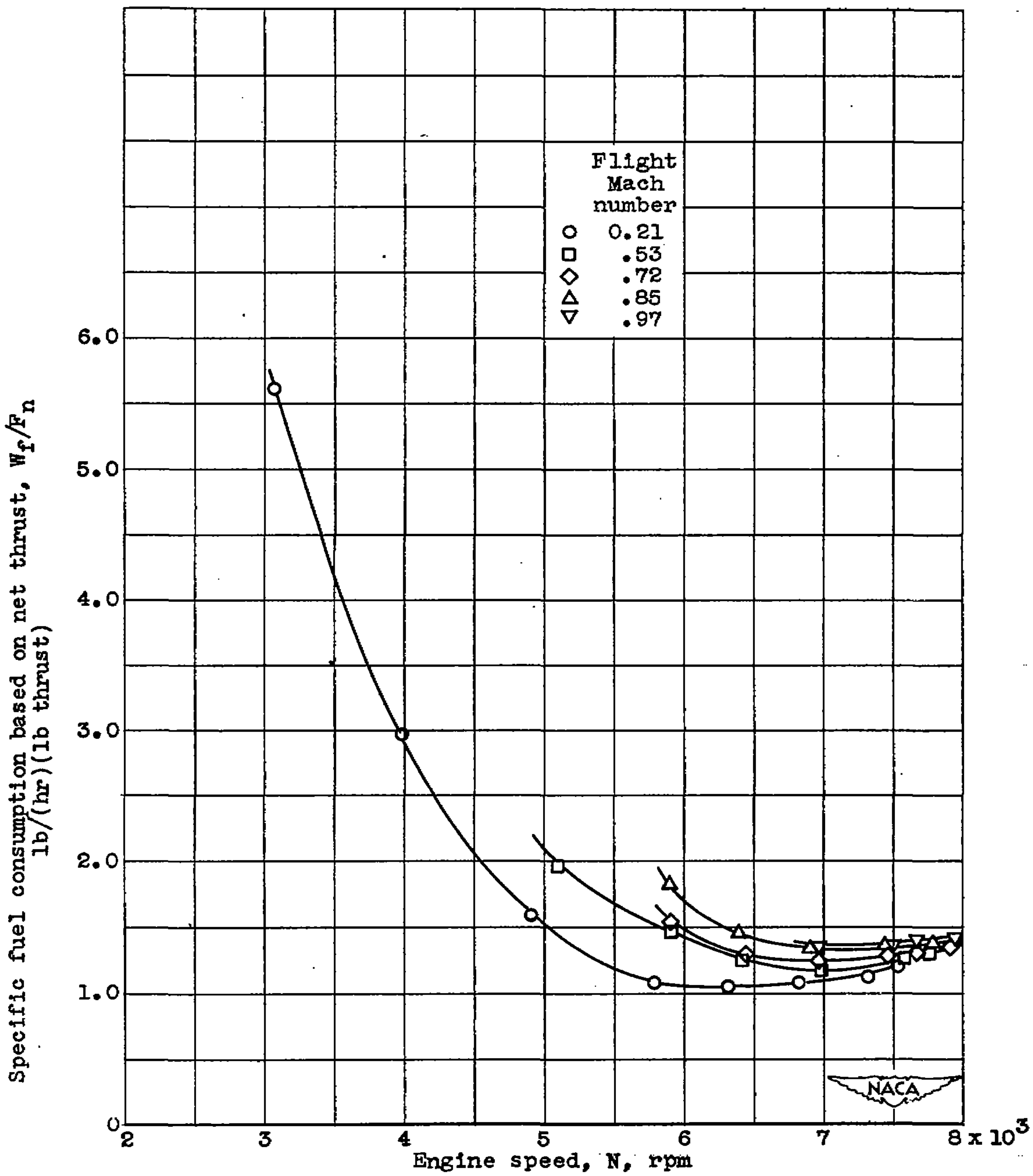
(b) Air flow.

Figure 5. - Continued. Effect of flight Mach number on variation of engine performance with engine speed at altitude of 25,000 feet.



(c) Fuel flow.

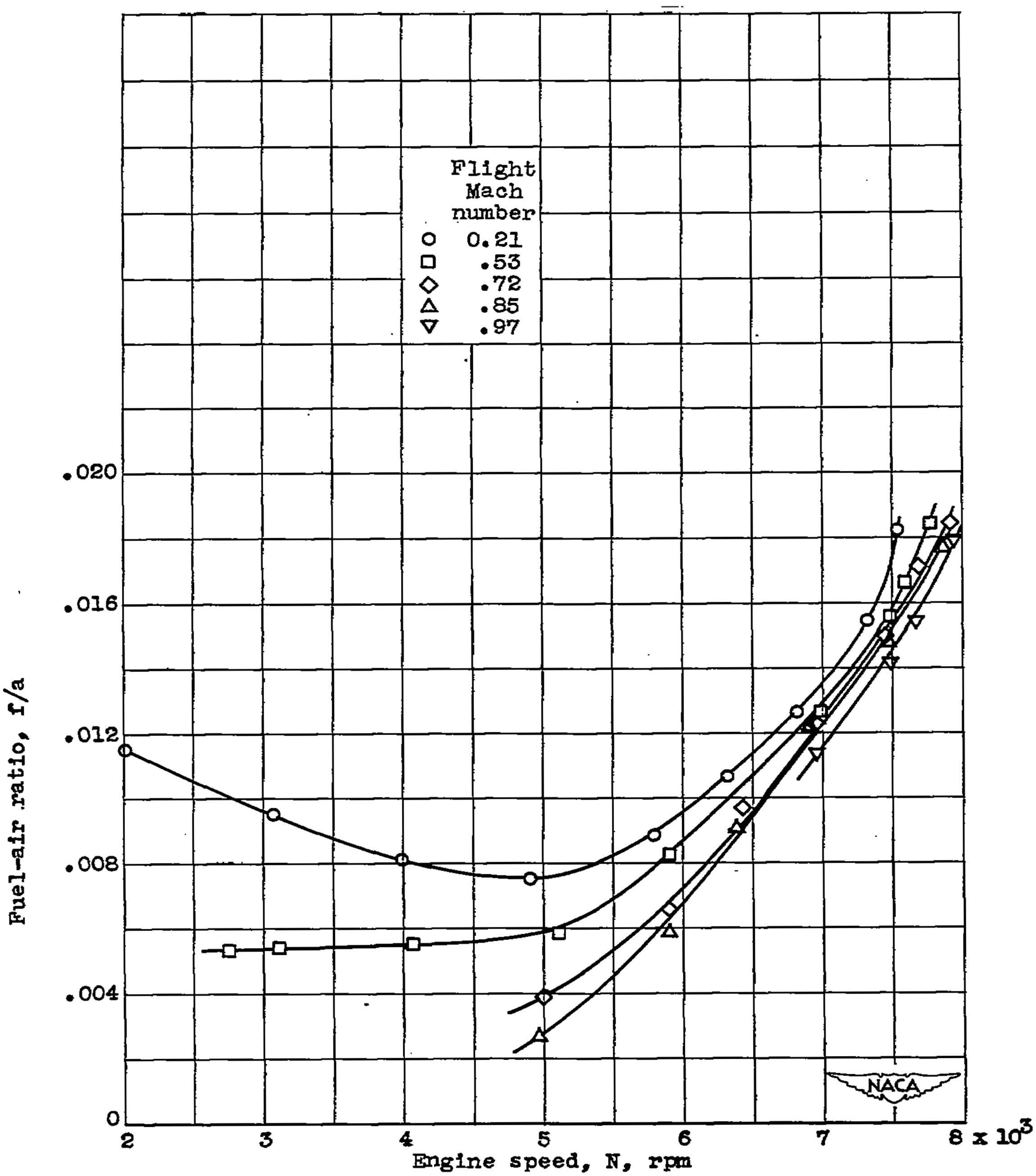
Figure 5. - Continued. Effect of flight Mach number on variation of engine performance with engine speed at altitude of 25,000 feet.



(d) Specific fuel consumption.

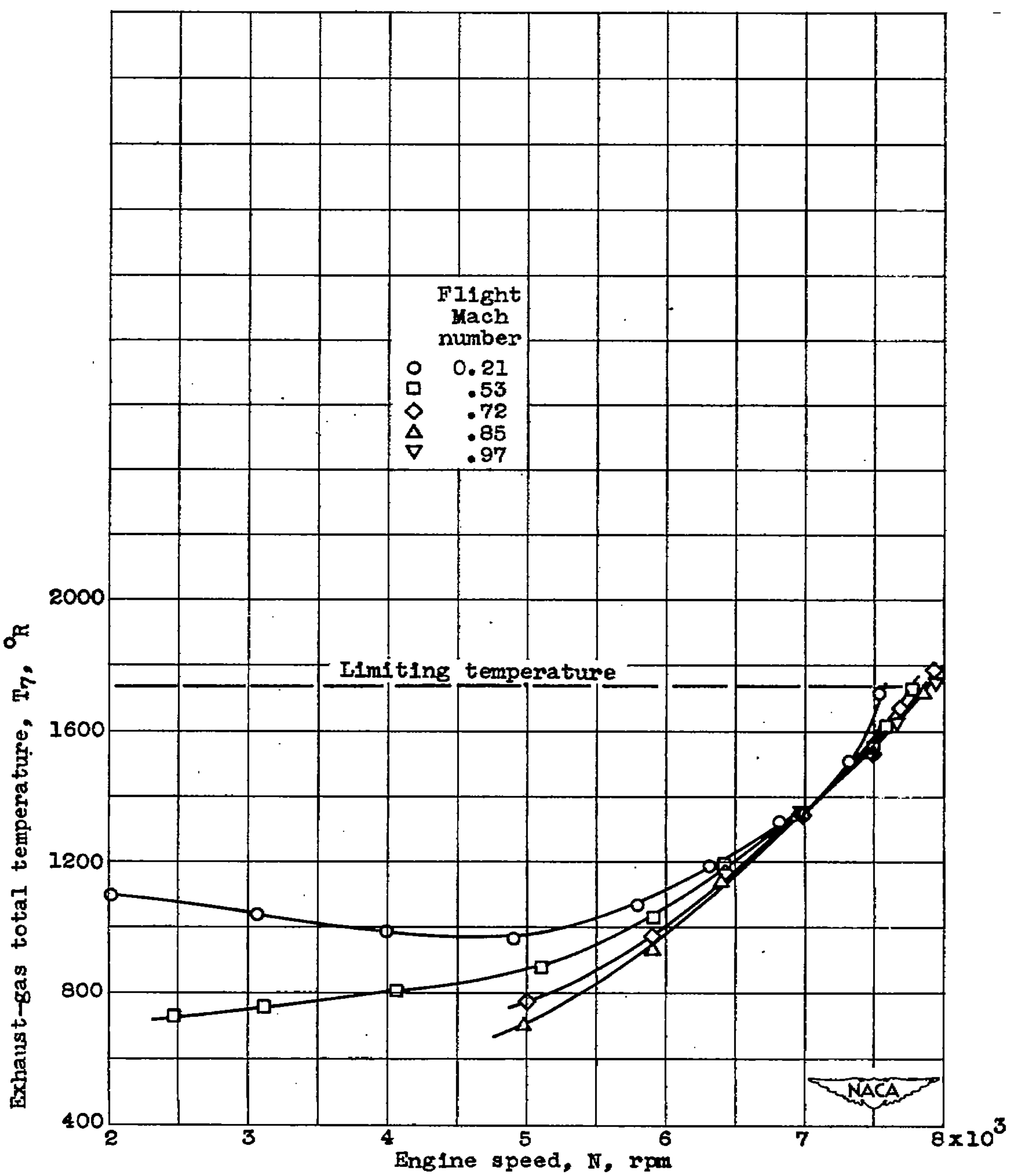
Figure 5. - Continued. Effect of flight Mach number on variation of engine performance with engine speed at altitude of 25,000 feet.

1159



(e) Fuel-air ratio.

Figure 5. - Continued. Effect of flight Mach number on variation of engine performance with engine speed at altitude of 25,000 feet.



(f) Exhaust-gas total temperature.

Figure 5. - Concluded. Effect of flight Mach number on variation of engine performance with engine speed at altitude of 25,000 feet.

1159

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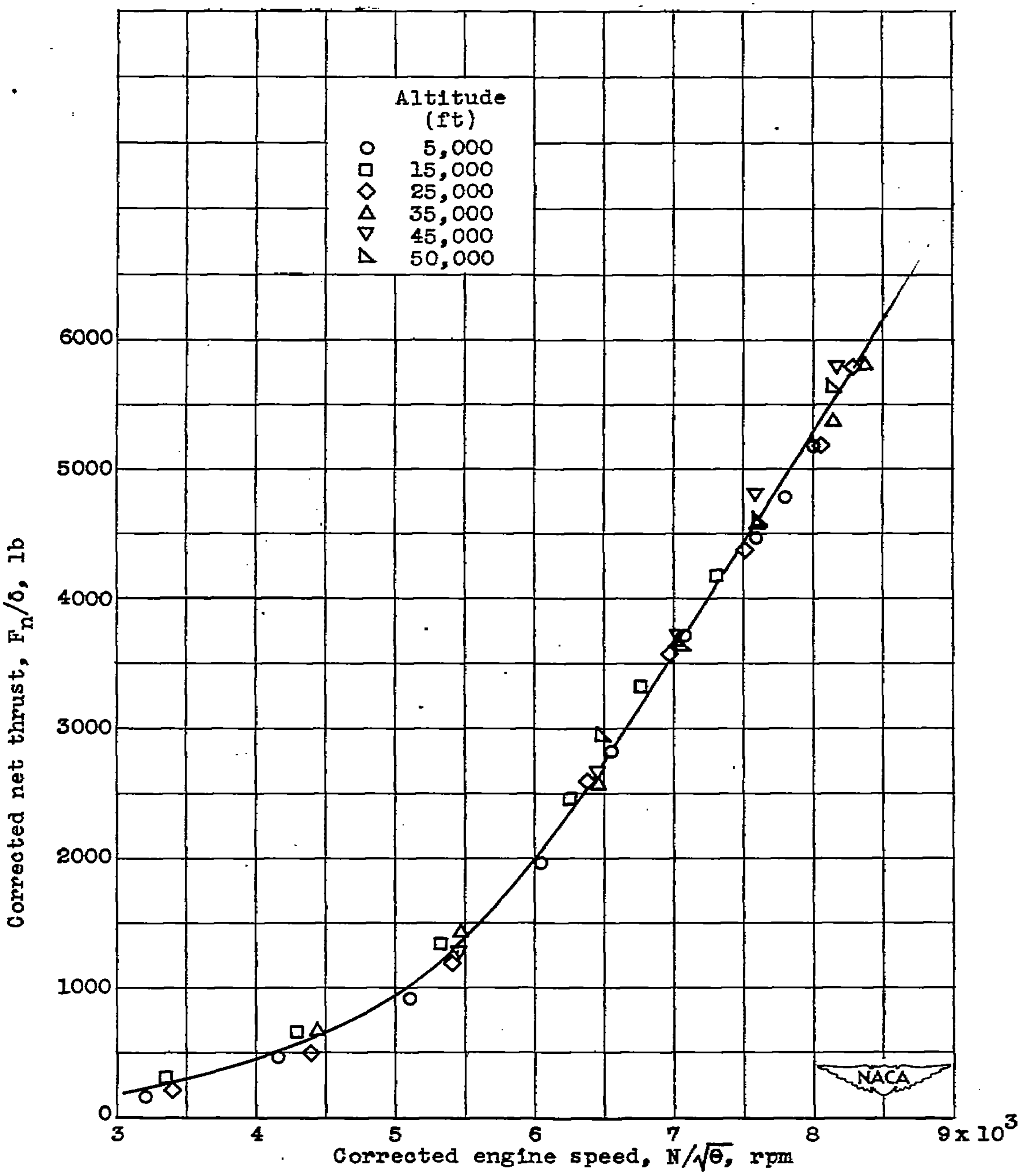
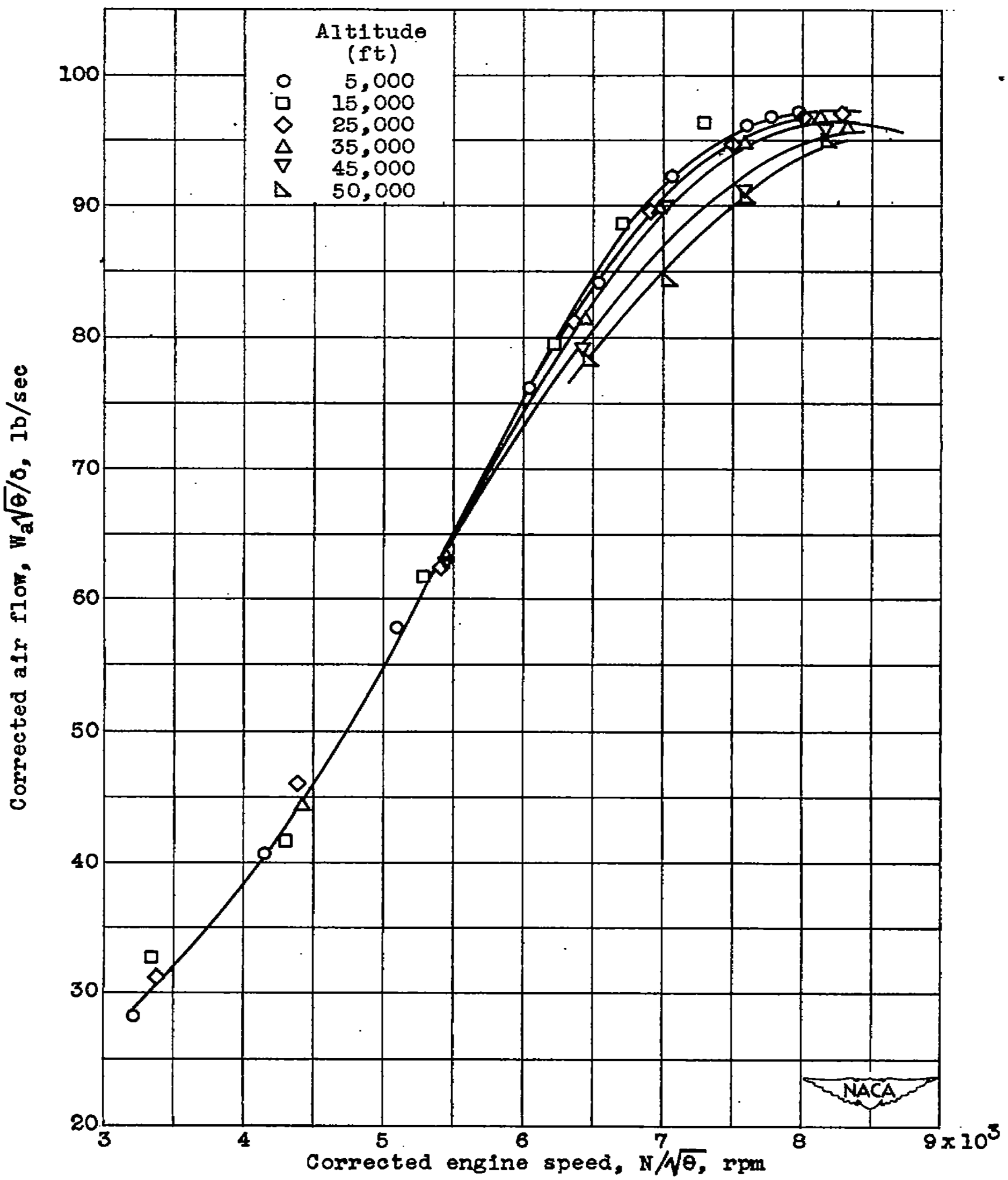


(a) Net thrust.

Figure 6. - Effect of altitude on variation of corrected engine performance with corrected engine speed at flight Mach number of 0.21.



(b) Air flow.

Figure 6. - Continued. Effect of altitude on variation of corrected engine performance with corrected engine speed at flight Mach number of 0.21.

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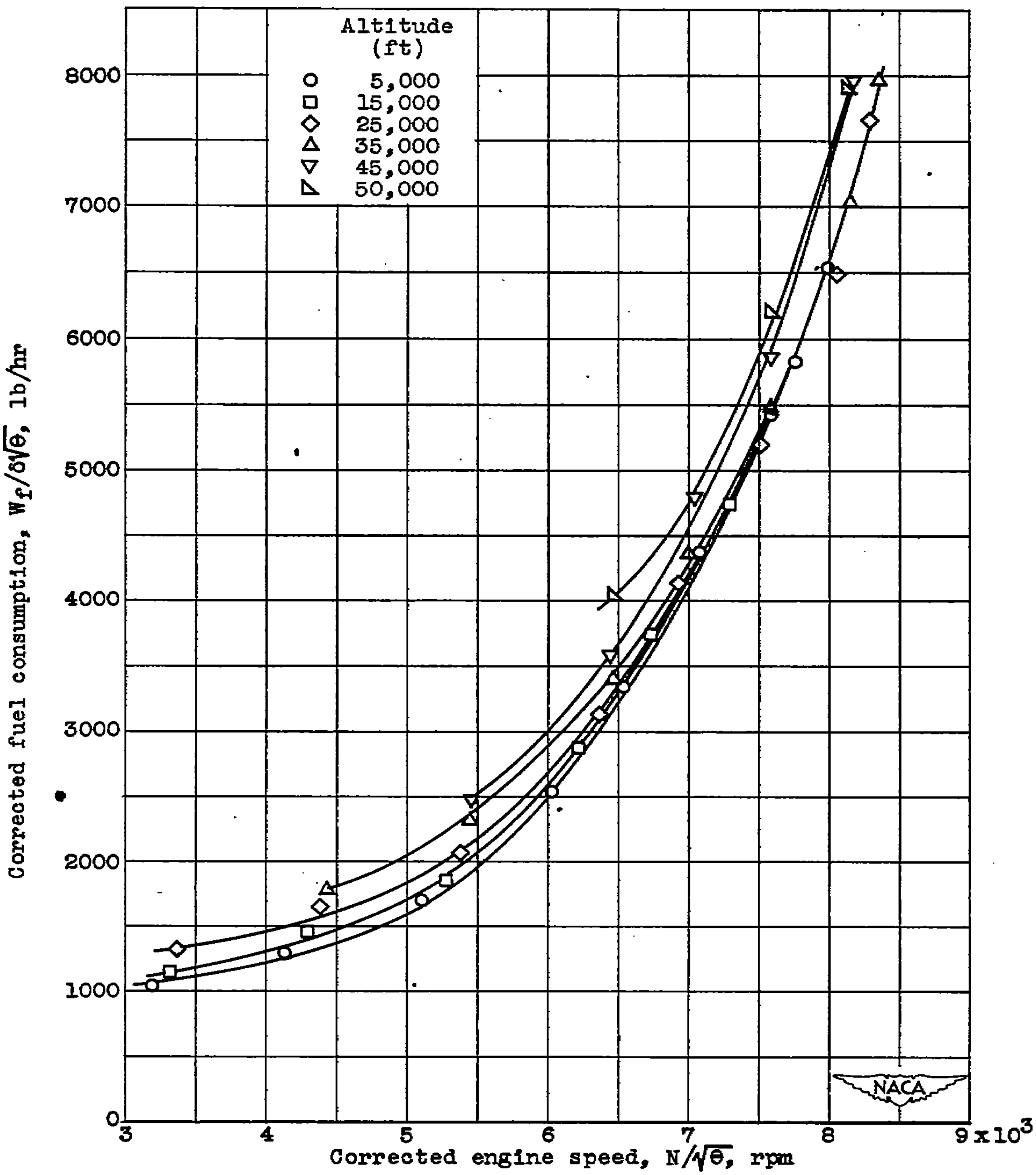
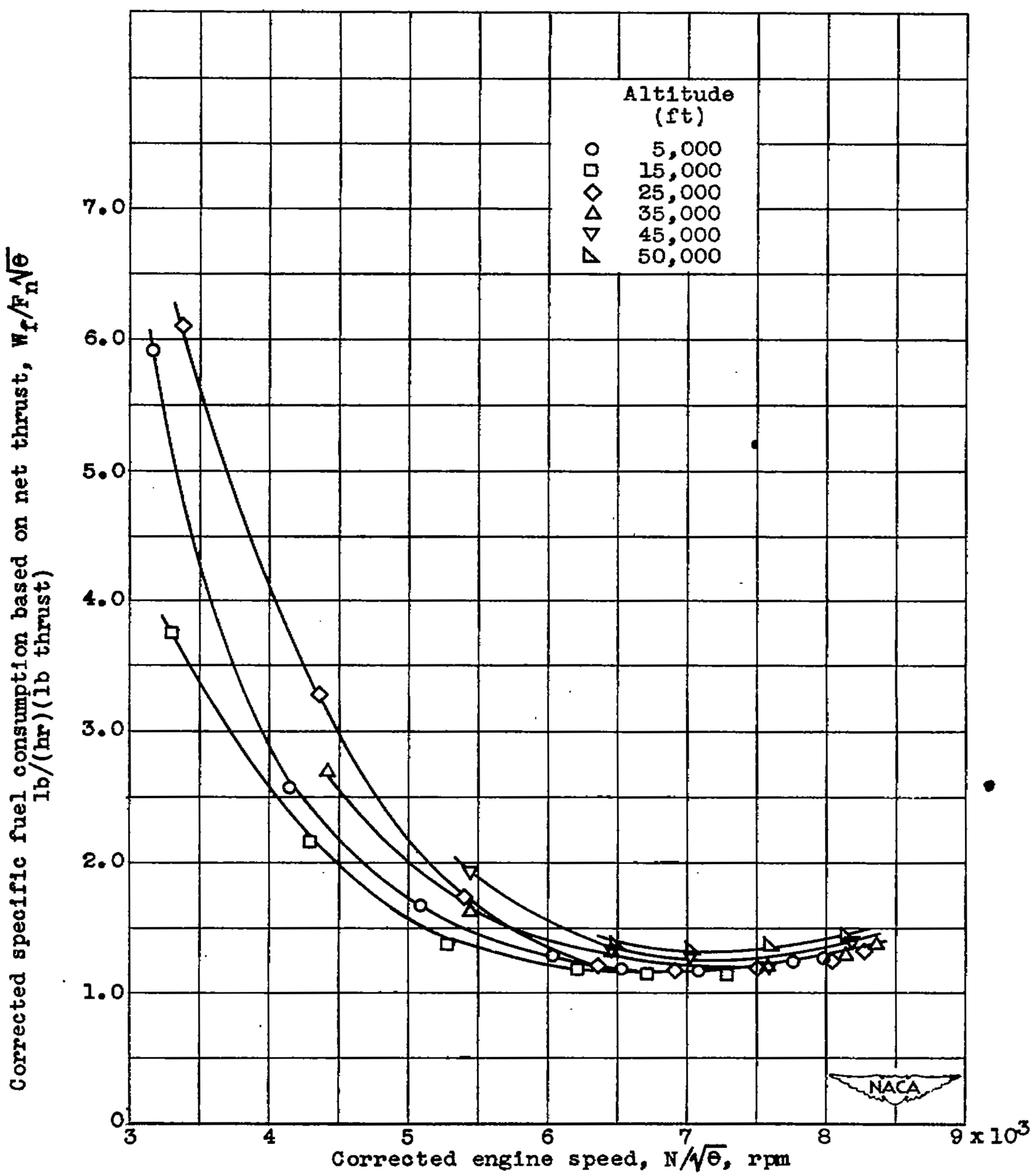


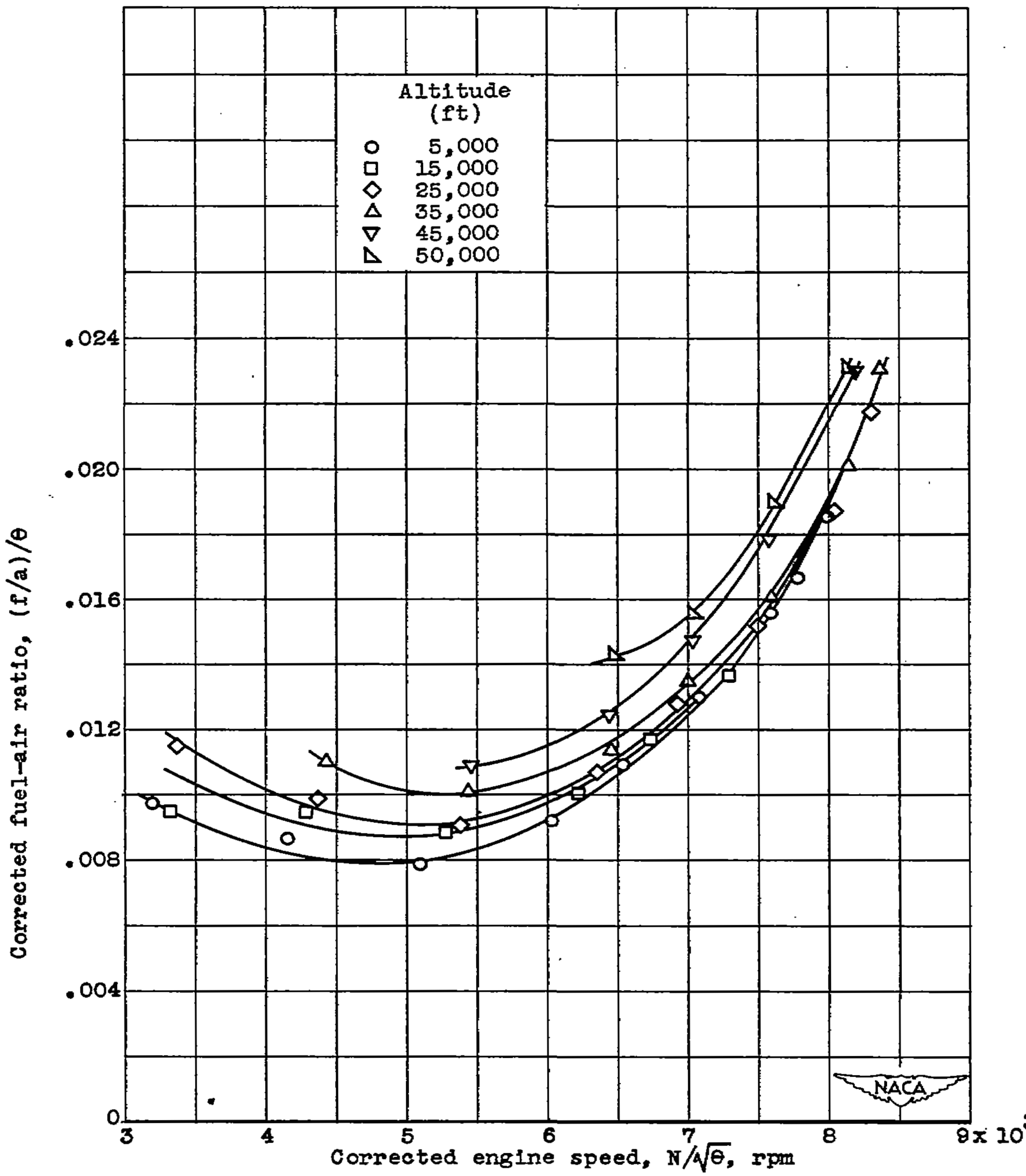
(c) Fuel flow.

Figure 6. - Continued. Effect of altitude on variation of corrected engine performance with corrected engine speed at flight Mach number of 0.21.



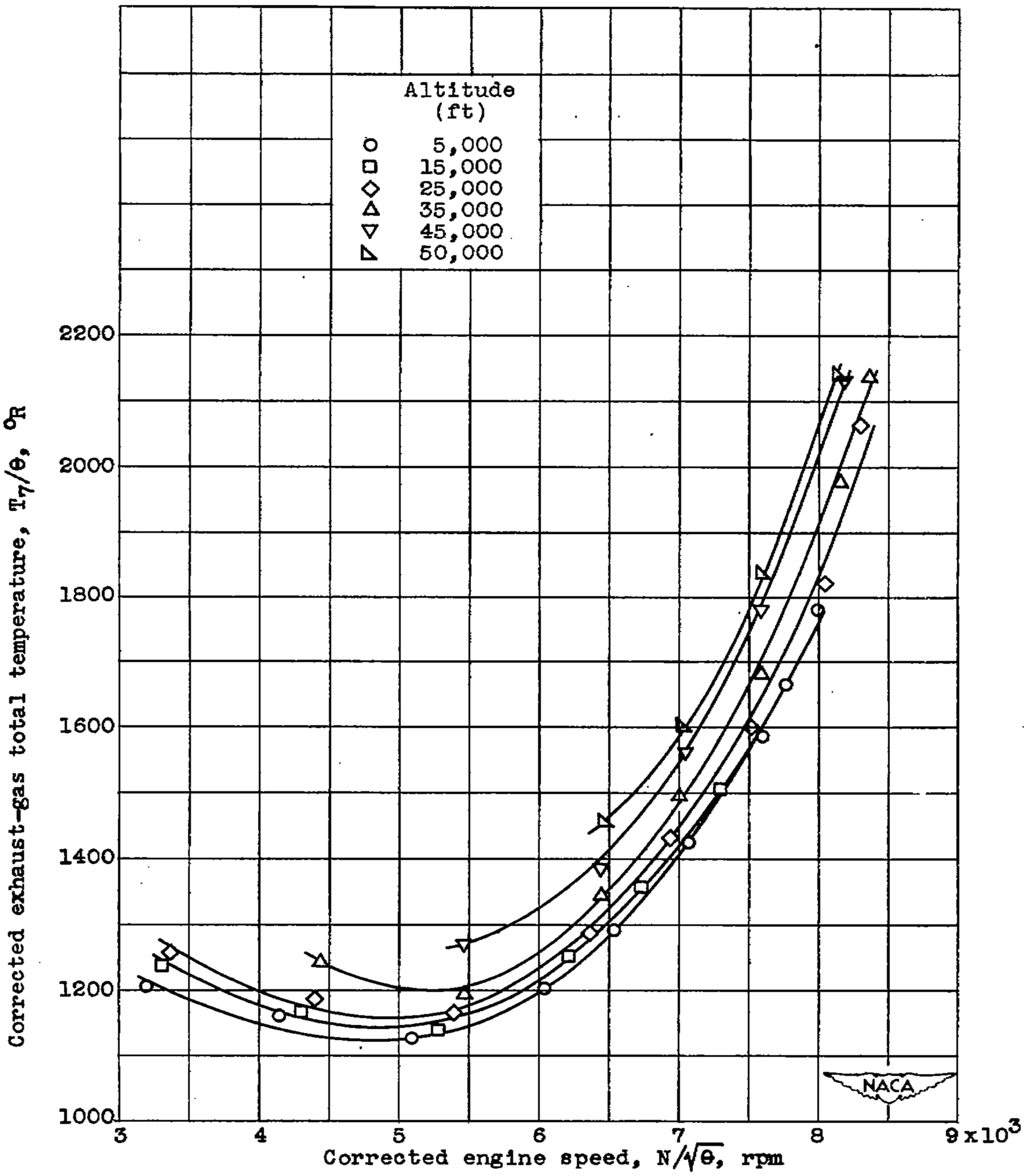
(d) Specific fuel consumption.

Figure 6. - Continued. Effect of altitude on variation of corrected engine performance with corrected engine speed at flight Mach number of 0.21.



(e) Fuel-air ratio.

Figure 6. - Continued. Effect of altitude on variation of corrected engine performance with corrected engine speed at flight Mach number of 0.21.



(f) Exhaust-gas total temperature

Figure 6. - Concluded. Effect of altitude on variation of corrected engine performance with corrected engine speed at flight Mach number of 0.21.

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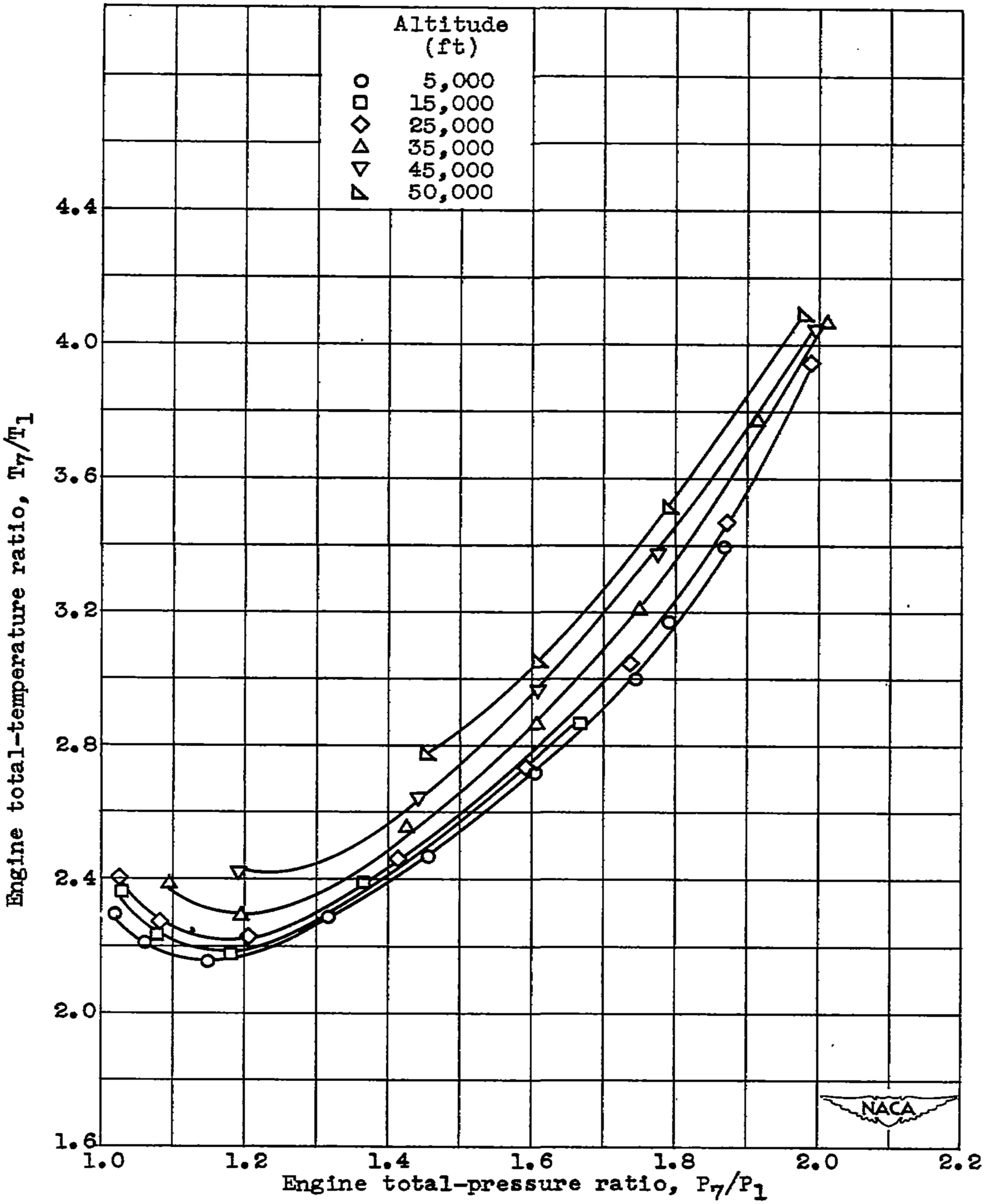

(a) Flight Mach number, 0.21; altitude, 5000 to 50,000 feet.

Figure 7. - Variation of engine total-temperature ratio with engine total-pressure ratio.

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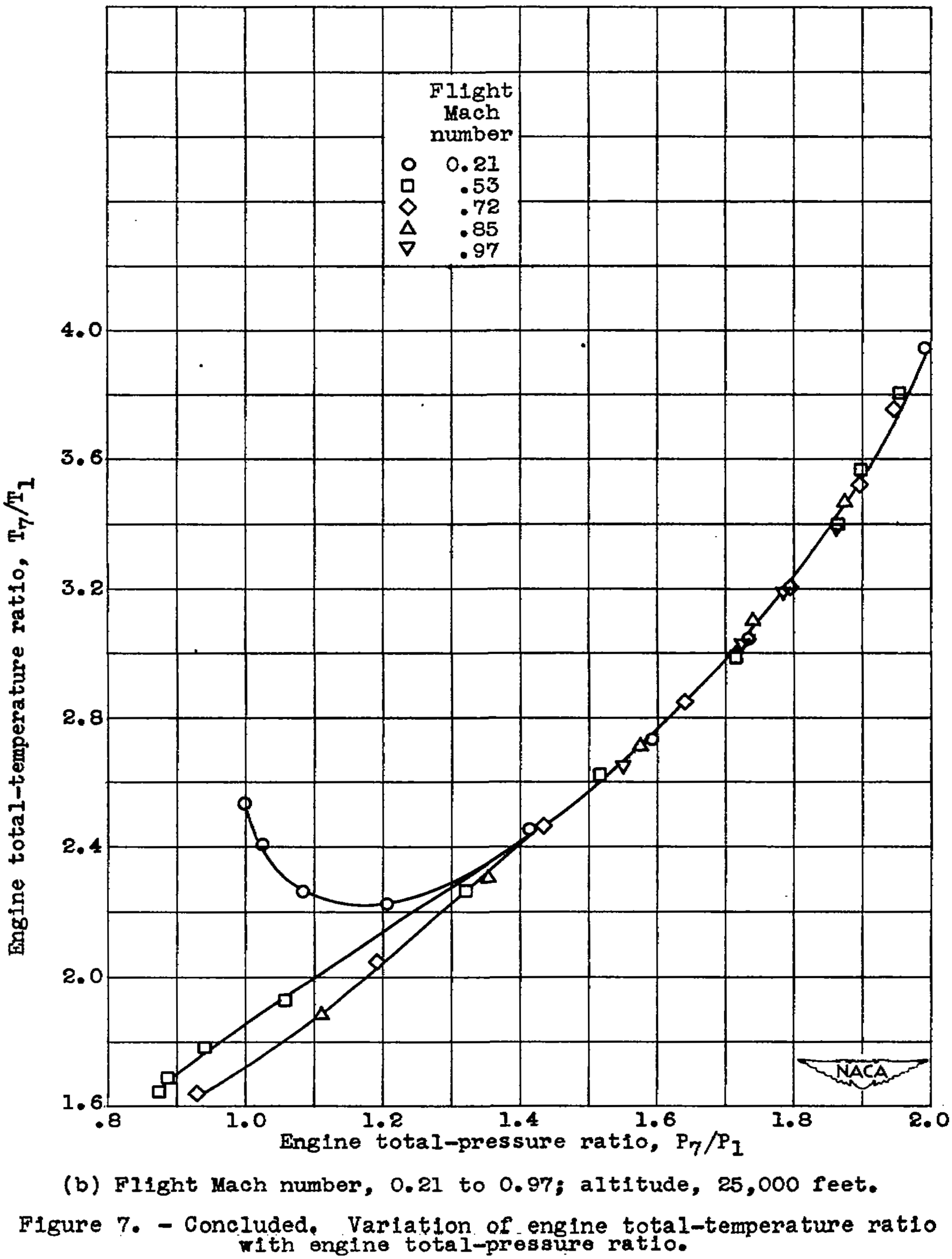

(b) Flight Mach number, 0.21 to 0.97; altitude, 25,000 feet.

Figure 7. - Concluded. Variation of engine total-temperature ratio with engine total-pressure ratio.

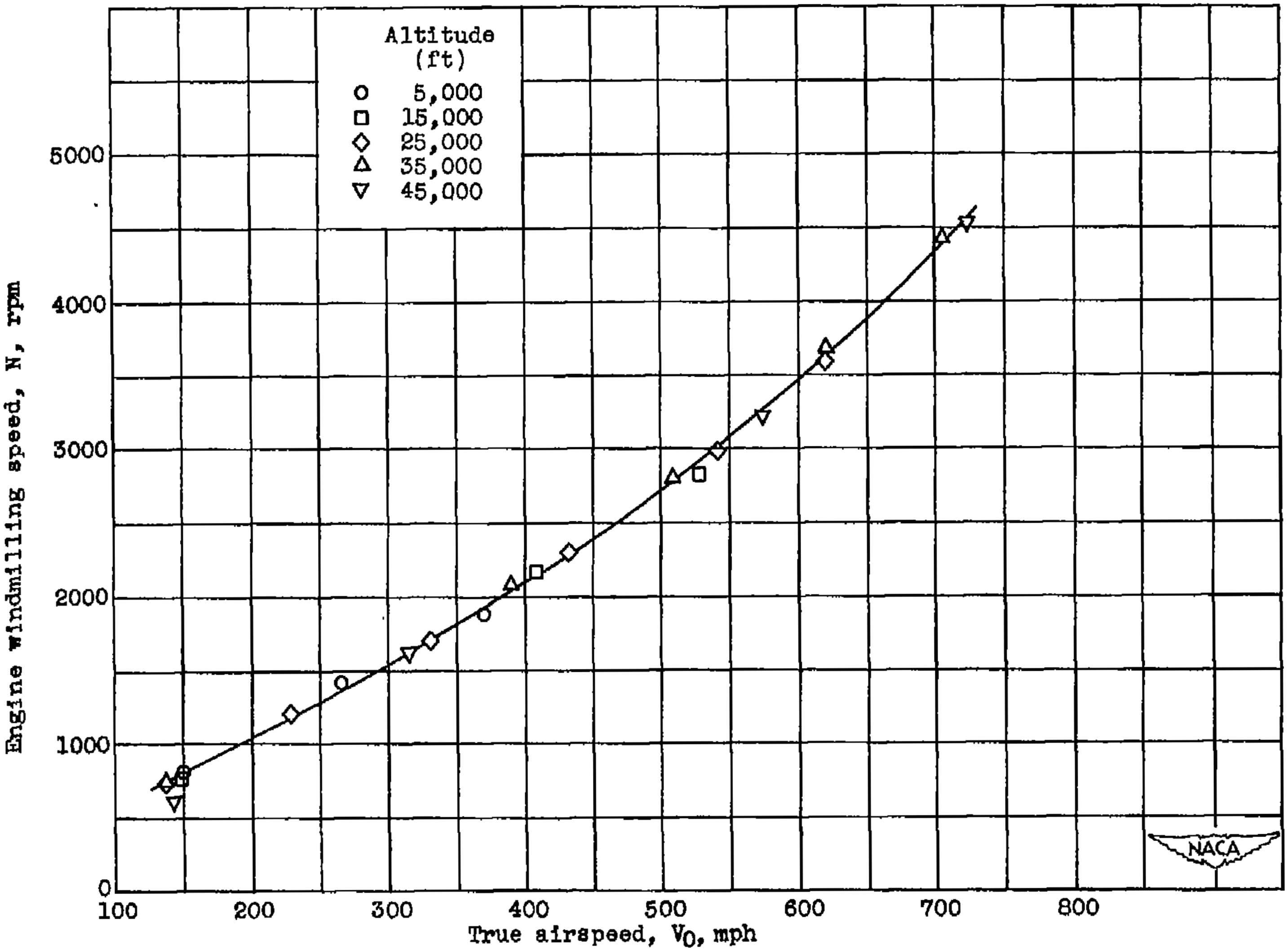

Figure 8. - Variation of engine windmilling speed with true airspeed at altitudes from 5000 to 45,000 feet.

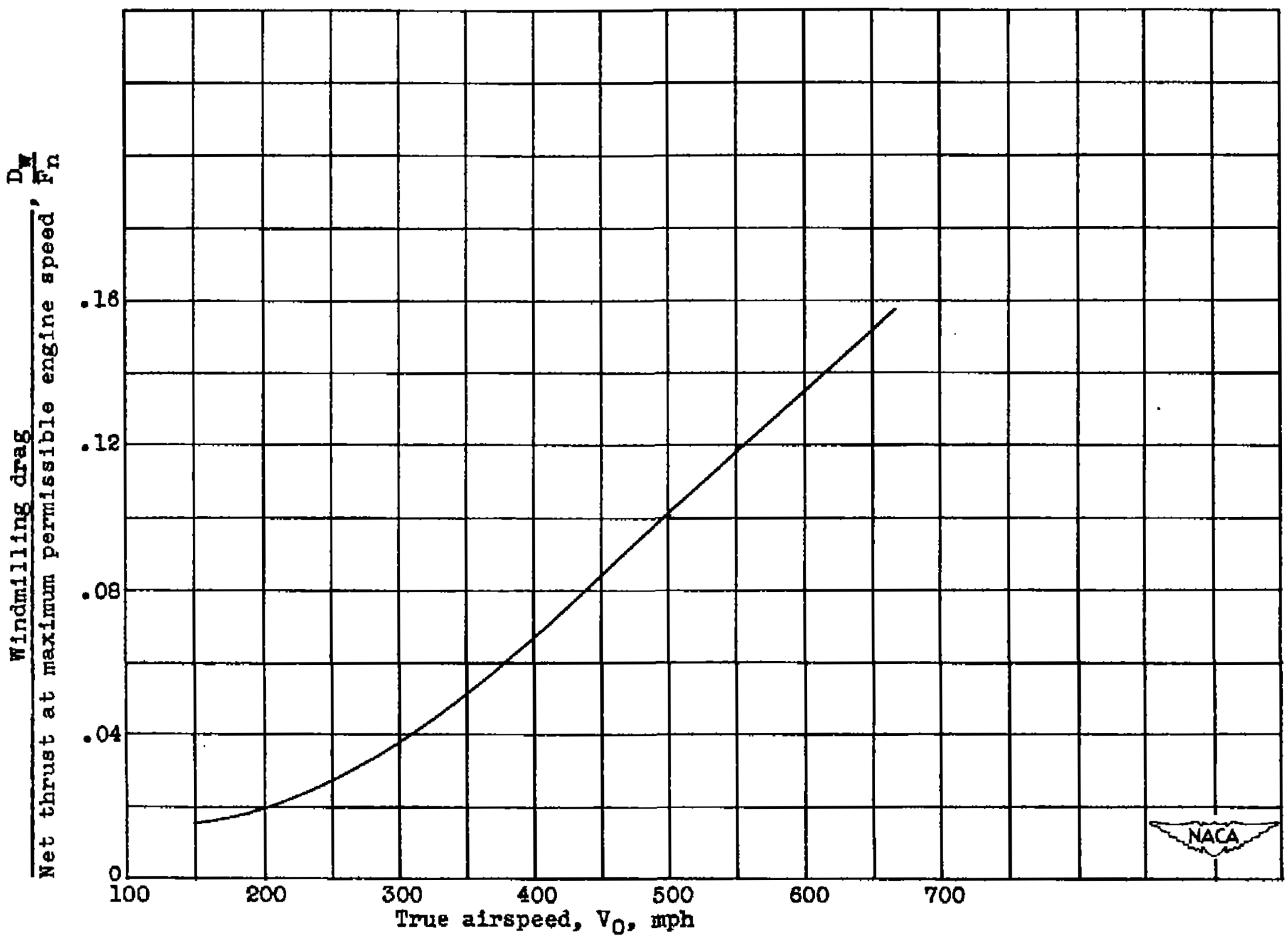

Figure 9. - Variation of ratio of windmilling drag to net thrust at maximum permissible engine speed with true airspeed at altitude of 25,000 feet.

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